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The building and application of a flexible CAD model for the DTU ECOCAR

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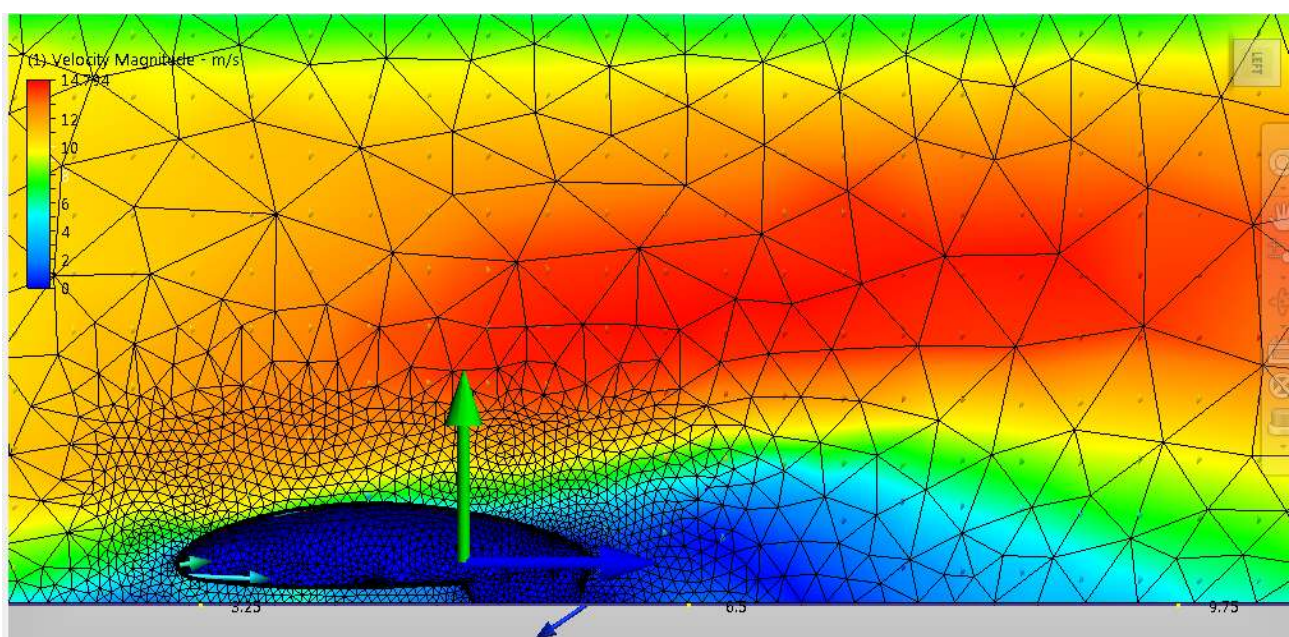
Design report

The building and application of a flexible CAD model for the DTU ECOCAR

Af Georg K. Christensen, DTU-MEKANIK,

17 februar 2016

Sektion for konstruktion og produktudvikling



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1) Introduction

The DTU Eco car has participated in The Shell Eco-Marathon competition at several occasions. The completion and rules thereof can be found at [ref.1 and ref 2]. It seem that the overall dimension for the car body seem to change slightly from year to year. The observed changes lead to a desire from the students to change the optimized model from previous year to be able to participate in the 2016 competition [ref. 3]. The winning car bodies from 2015 and associated fuel-types are shown in fig. 1

Battery-electric



Technische Universitaet Muenchen
TUFast ECO TEAM - 863km/kWh
(a)

Alternative fuel



Universitat Miguel Hernandez D'Elx
EQUIP UMH - 1496 km/l
(b)

CNG



Lycee Saint-Joseph La Joliverie
MICROJOULE-LA JOLIVERIE - 2584km/l
(c)

Diesel



I.U.T Valenciennes
IUT GMP VALENCIENNES - 1323km/l
(d)

Gasoline



Airbus Helicopters Centre de Formation Technique
TED - 2308 km/l
(e)

Hydrogen

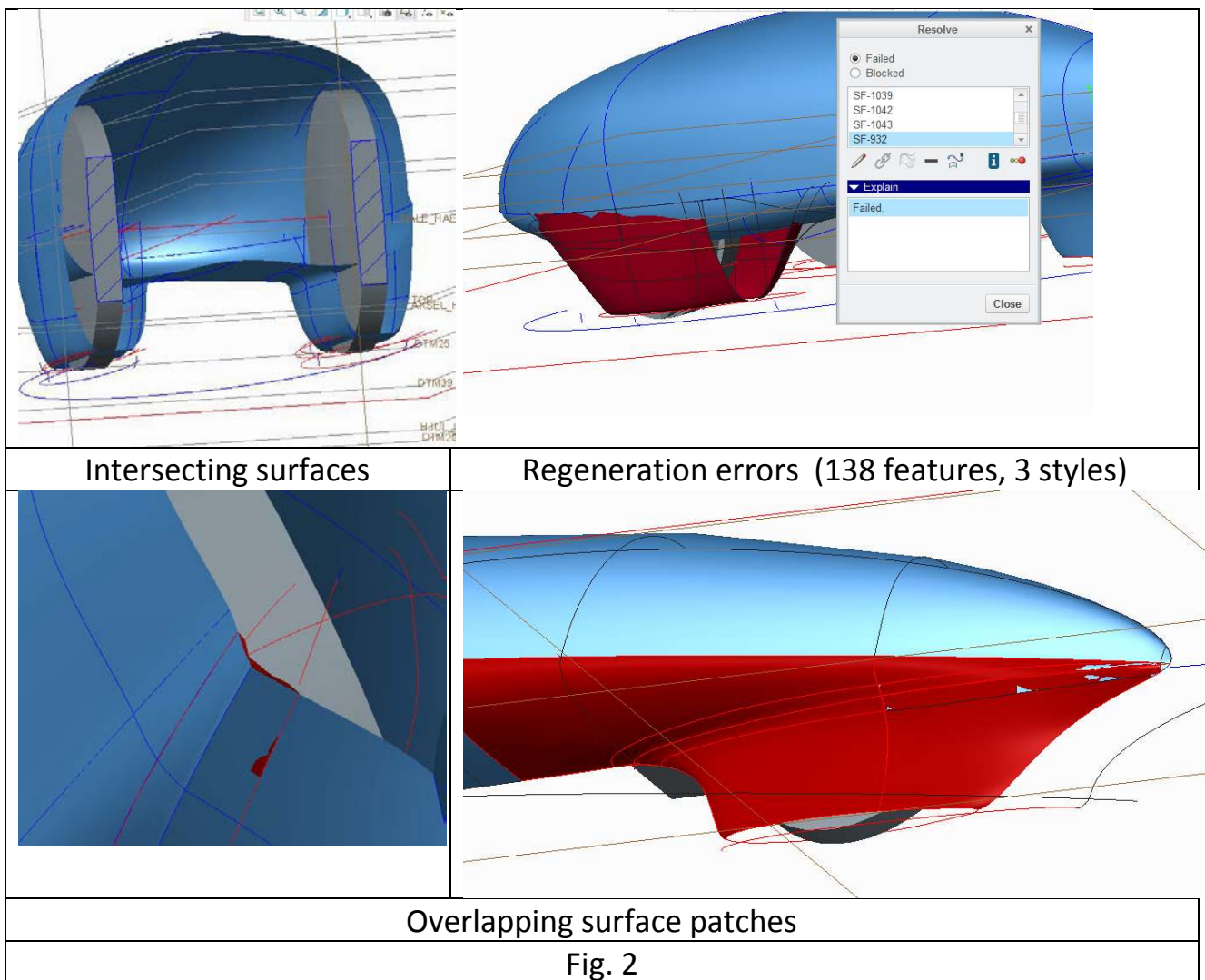


Delft University of Technology
ECO-RUNNER TEAM DELFT- 1227 km/m³
(f)

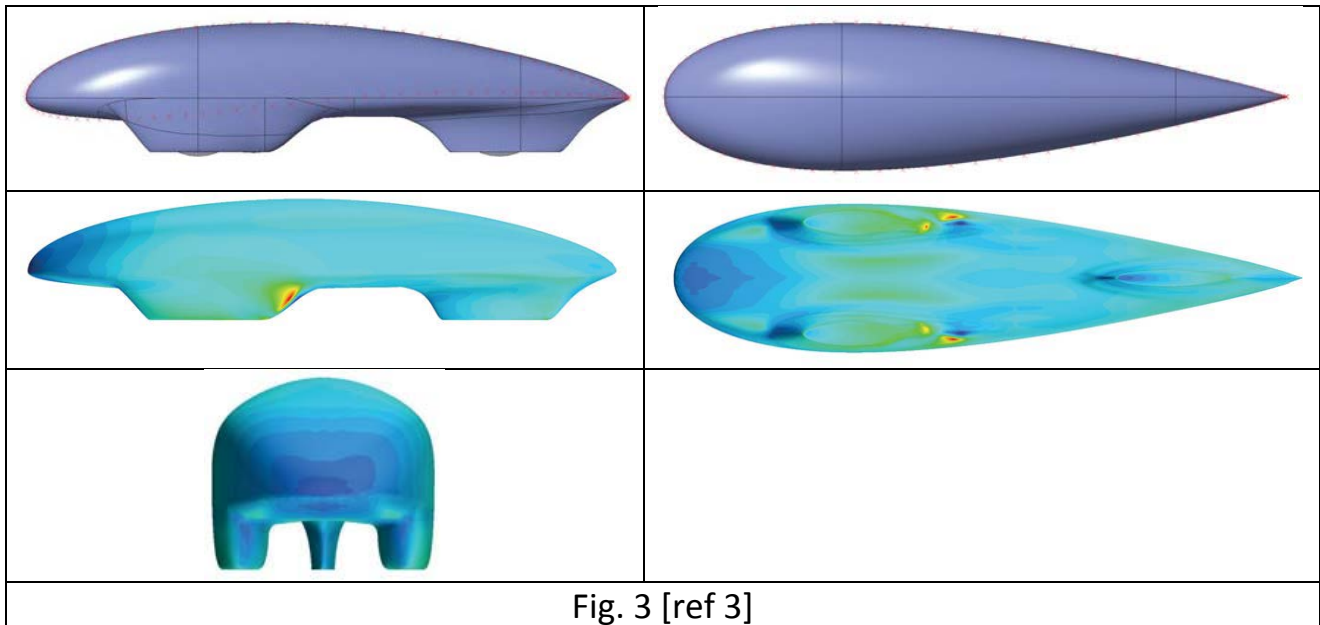
Figure 1: Winner prototypes of the 2015 European Shell Eco-marathon
(adapted from ref[3])

Inspection of the CAD model which was modeled using PTC's parametric CAD system: Creo 3.0 showed that the model was suffering from a number of serious drawbacks. First the model was made using overlapping surface patches. Any attempt to make modifications lead to series of surface reference loses.

The consequence is that the model cannot be given thickness or solidified which became necessary due to the desire to manufacture the 2016 body using carbon fiber. After a number of trails we had to conclude, that it was impossible to modify the existing surface model in order to achieve a faultless version thereof. A figure showing overlapping surface patches and failing surface regeneration is shown in fig. 2.



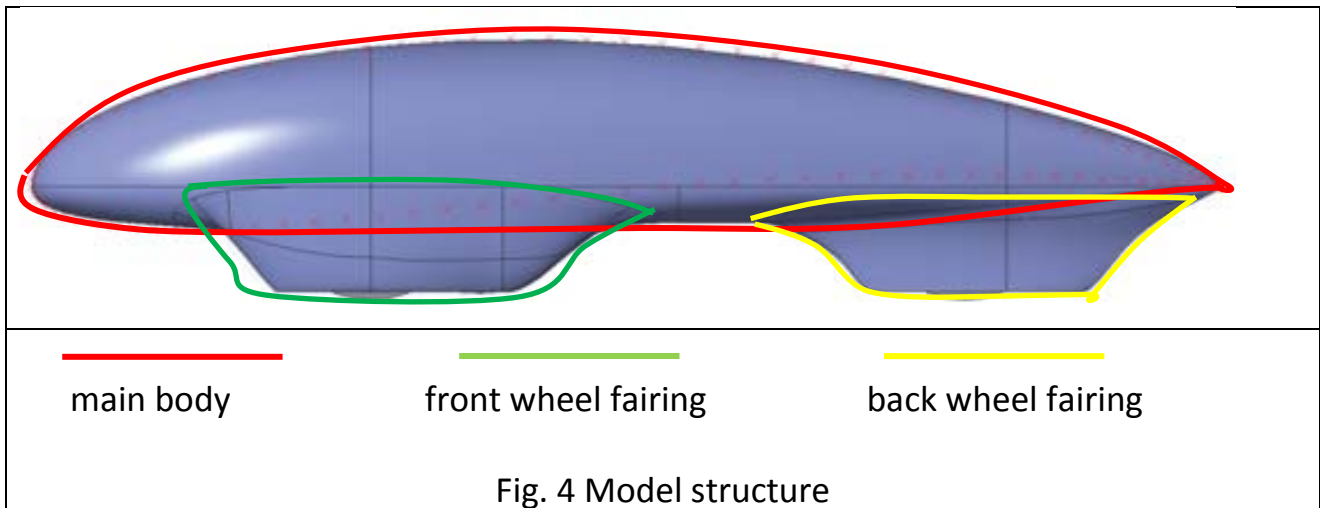
Although there has been a lot of different car shapes for the Shell Eco-Marathon (Fig. 1) it has been decided to continue to search for car structures similar to the structure in fig. 3. CFD-calculations for this structure have shown that the drag coefficient, C_d for this can be lowered to about 0.108 which was judged to be acceptable



2) The Model plan

From the experiences for the previous model it was concluded that the buildup of the model in one STYLE-feature should be abandoned. A STYLE feature in Creo is a collection of curves and surfaces that will be updated interactively. A structure with more than one STYLE feature was accepted in an attempt to lower the influence of changes, where one slight change say from curvature connections to the back of the body would make the wheel case at front of the body “fall off”. It was therefore decided first to make the main body without the wheel casings and then later attach the wheel cases using independent style features. This means that the model gets spilt up as shown in figure 4.

It would be nice from a CAD model perspective, if it was possible to make a model of the main body and use that model for CFD-calculations and optimization. However the experts of CFD calculations pointed out [ref. 6] that the total body should be present before an optimization could be undertaken. The structure in fig. 4 is therefore perhaps not optimal in a CFD-sense, but if it was judged be necessary in



order to create a robust and flexible CAD model. The consequence is that the model must be modified using different STYLE-features in Creo.






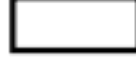



2.1) The main body build-up

The main body is symmetric and we can therefore concentrate in building a half – model. A number of parameters were given for the new model using the old fragile CAD model. The new set of parameters is given in table 1.

| ECO-car specifications | mm |
|--|----------------------------------|
| sporvidde | 500 |
| Total lenght | 2800 |
| Distance between front and rear axel | 1400 |
| Distance from FRONT to front axel | 800 |
| Wheel diameter incl. tyres | 498 |
| Steering angle | $\pm 13^\circ$ from P_T |
| P_T on FRONT axle | ± 100 mm from symmetry plane |
| Horizontal Body center distance from ground | 249 |
| Wheel case distance to ground | 20 |
| Table 1: parameter set for the Shell ECO-Marathon 2016 | |

A set of section drawings of the old model were created. A couple of there are shown in appendix. 1

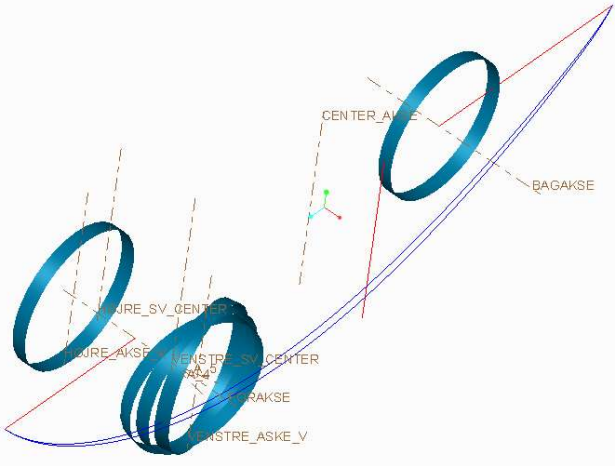
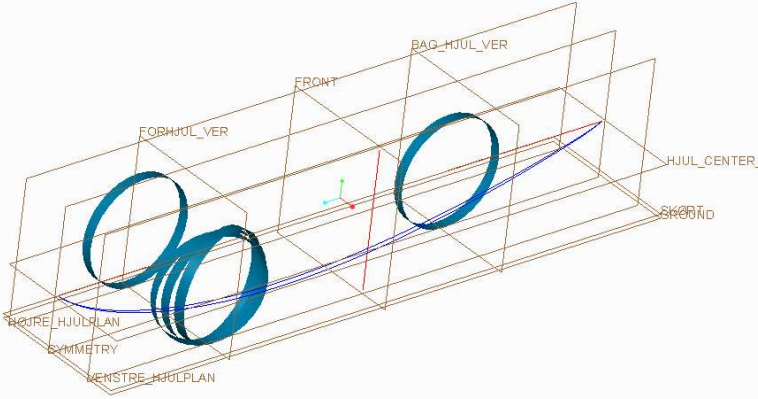
It is clear that the horizontal section at the body center tries to follow a streamlined body profile. A general guide is shown fig. 5. A NACA-15 profile was used after scaling to a body length of 2800 mm. The profile data is shown in Table 2. This profile can be entered directly into CREO using a set of control points like table 2.

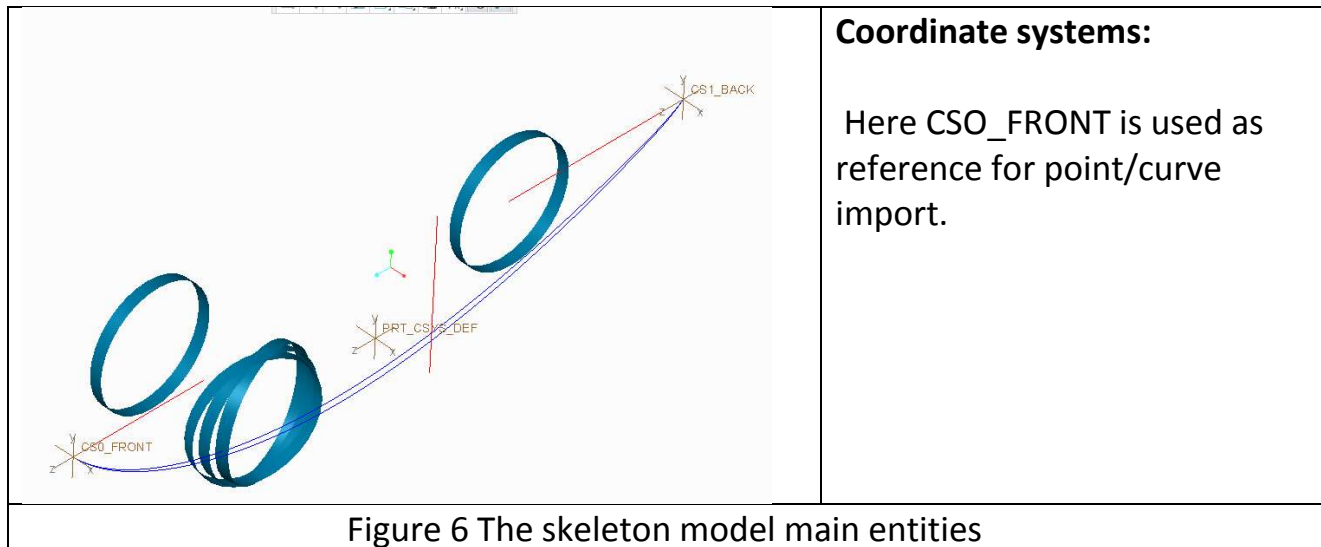
| | | | | | Shape | | Drag Coefficient |
|---|---------|---------|------|-------|---|---|------------------|
| nr | X mm | X*1.075 | Y mm | Z mm | | | |
| 1 | 0 | 0 | 0 | -2800 | Sphere |  | 0.47 |
| 2 | 47.376 | 50.9292 | 0 | -2660 | Half-sphere |  | 0.42 |
| 3 | 85.07 | 91.450 | 0 | -2520 | Cone |  | 0.50 |
| 4 | 154.113 | 165.671 | 0 | -2240 | Cube |  | 1.05 |
| 5 | 215.26 | 231.405 | 0 | -1960 | Angled Cube |  | 0.80 |
| 6 | 268.088 | 288.194 | 0 | -1680 | Long Cylinder |  | 0.82 |
| 7 | 310.999 | 334.324 | 0 | -1400 | Short Cylinder |  | 1.15 |
| 8 | 340.938 | 366.508 | 0 | -1120 | Streamlined Body |  | 0.04 |
| 9 | 352.594 | 379.039 | 0 | -840 | Streamlined Half-body |  | 0.09 |
| 10 | 349.069 | 375.249 | 0 | -700 | Measured Drag Coefficients | | |
| 11 | 337.084 | 362.365 | 0 | -560 | | | |
| 12 | 314.054 | 337.608 | 0 | -420 | | | |
| 13 | 275.091 | 295.723 | 0 | -280 | | | |
| 14 | 246.75 | 265.256 | 0 | -210 | | | |
| 15 | 208.821 | 224.483 | 0 | -140 | | | |
| 16 | 153.596 | 165.116 | 0 | -70 | | | |
| 17 | 111.249 | 119.593 | 0 | -35 | | | |
| 18 | 0 | 0 | 0 | 0 | | | |
| Table 2 Data from NACA profile[ref. 5] | | | | | Figure 5 Bodies and C_D coefficients [ref. 4] | | |

The insert is executed by the command: Get Data/ Import. A spline will be created through the points. The file can be created using Microsoft NOTEPAD followed by a change of the file extension from *.txt to *.ibl. A version of the file is given in

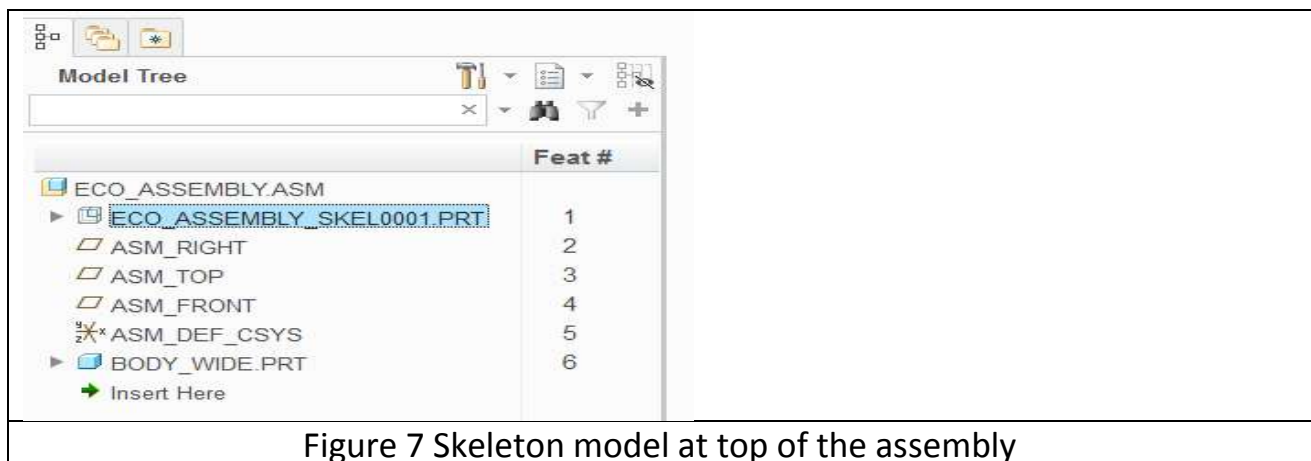
Appendix 1. The reason the length values Z are negative is the position of the reference coordinate system which is at the main body front.

We will now proceed to the presentation of the model structure. It has been decided to use the skeleton approach for modeling the car body. The reason for this is that the reference geometry for the CAD which consists of datum planes, datum points, curves and surfaces are kept conveniently at the skeleton level and therefore a separate editable entity which can be modified individually and can be hidden at assembly and part level when this is convenient. The skeleton model is presented in figure 6 in three steps. The steps are: The axis presentation, the datum plane presentation and the coordinate system presentation. Notice the wheel representation via cylindrical surfaces. On the left side of the vehicle the maximum and minimum steering angle are represented by two additional cylindrical surfaces.

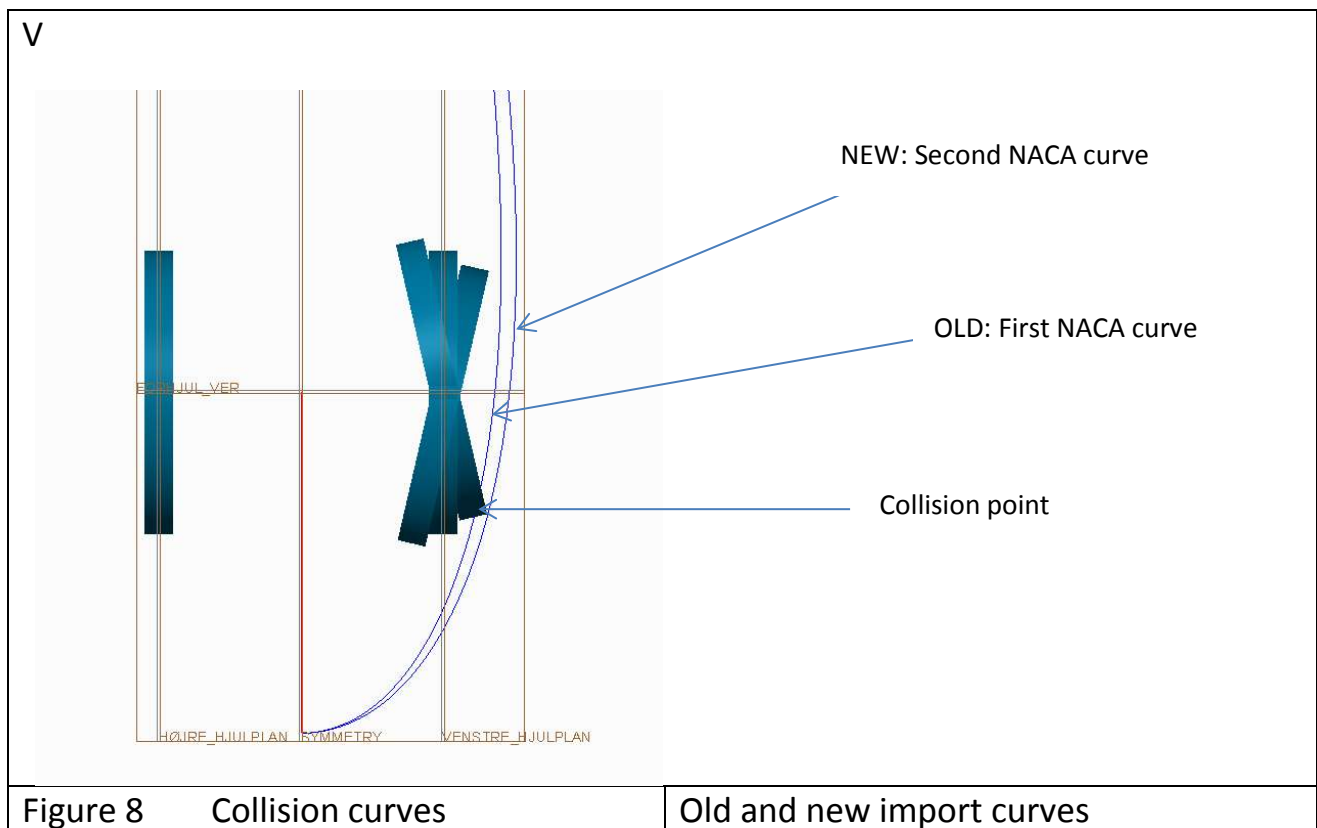
| | |
|---|--|
|  | <p>Datum Axis: CENTER_AXIS, BAGAKSE, FORAKSE, HØJRE_AKSE_V, VENSTRE_AKSE_V Wheel turn axis: HØJRE_SV_CENTER, VENSTRE_SV_CENTER</p> |
|  | <p>Datum planes: SYMMETRY, VENSTRE_HJULPLAN, HØJRE_HJULPLAN FRONT, FORHJUL_VER, BAGHJUL_VER GROUND,HJUL_CENTER, SKØRT</p> |



The overall structure/model tree is shown in fig. 7



In figure 8 the situation following the import is shown. As it can be seen there are two imported curves. This is because the first NACA profile cuts through the left steering wheel at a left turn. An extension of the NACA-profile by 7.5 % in the X-direction seems to solve the problem. It should be noted, that the replacement of one NACA-curve with another causes major update problems by the surface design. The problem is that even though it might be possible to replace the first curve with the second on a surface definition, the internal cross-curves all loose their references. It has also been tried to change the points in the original IBL-file and regenerate the model. This is done by regenerating the “curve_from_file” feature in the model tree. By this we are not allowed to switch the reference file to a new file.



If we however change the data of the original IBL-file we can now click at FILE and press OK in the File association box and force Creo to update the curve and follow the new data. The updated curve will be shown. However - also this update seems to create problems downstream. First the curve reference is lost in the Publish feature and if it is replaced here and propagated via Copy in the body part – the problem remains that the STYLE feature will loose references. The skeleton model contain about 34 features

2.2) Longitude curve design

With the import of a NACA-profile for the horizontal axis plane we need curves to mark the top and bottom profile of the main body. The curves should be planar on the SYMMETRY-plane. To approach the former design profiles a planar cross section picture from this model was made. The picture is shown in fig. 9.

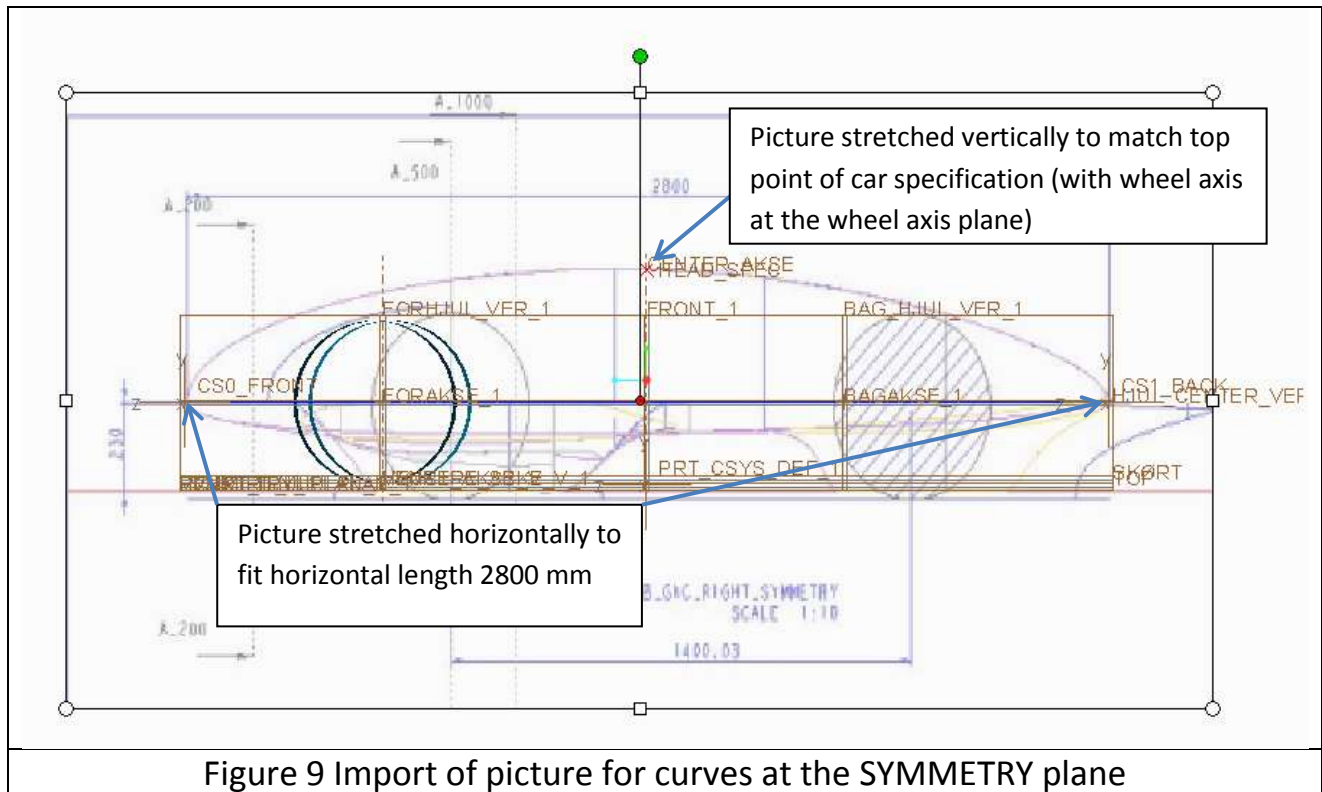


Figure 9 Import of picture for curves at the SYMMETRY plane

Most critical by the following STYLE curve definitions is that the curves are connected at the horizontal NACA-curve and that the top- and bottom curves are connected at FRONT.prt and BACK.prt. Following the two planar cross curves are defines one at the front of the body and one at the back. Make sure the sketch planes are defined well ahead of the FRONT wheels and well behind the BACK wheel. Now the overall main body surface can be defined. See figure 10. In between put a number of additional planar cross curves. Be sure they connect at all three longitudinal curves and that the tangents at the endpoints are normal to SYMMETRY. The first surface can now be made from 4 curves. See fig. 11. As soon as the surface is made, it can be modified and the NACA-profile and the additional cross curves should be added as internal curves. See fig. 12.

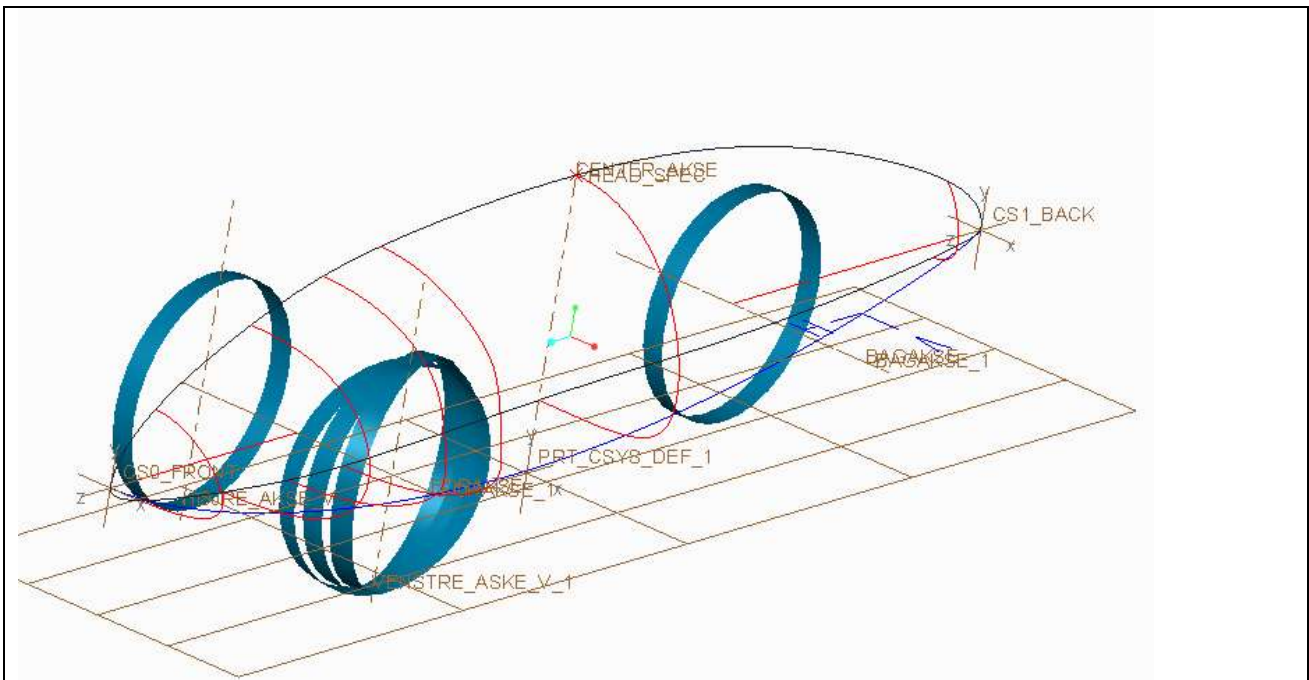


Figure 10 Overall body surface

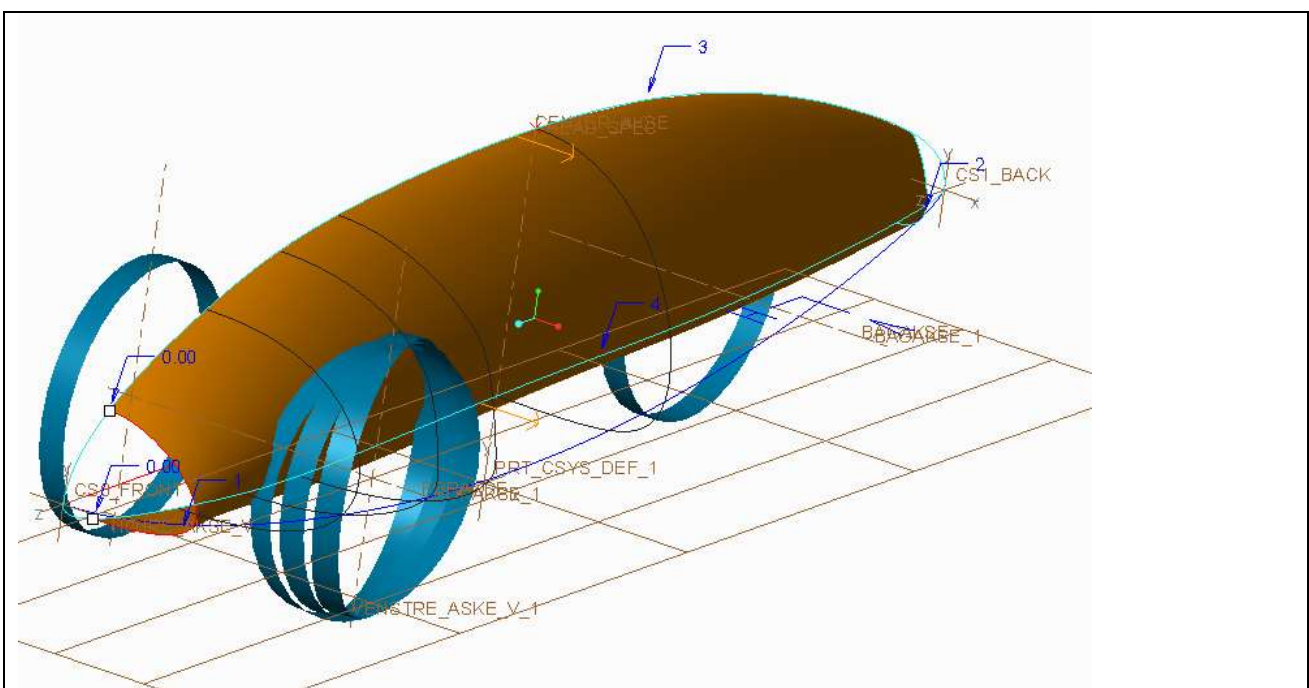


Figure 11 Initial main body surface

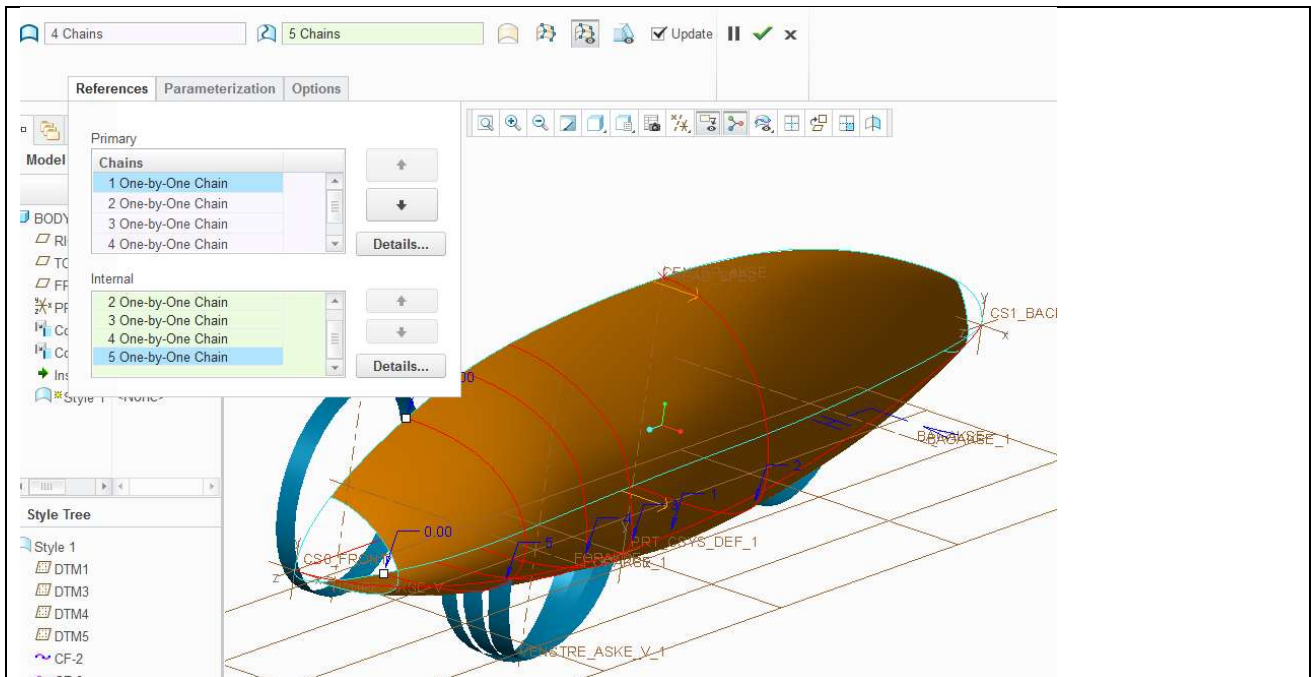


Fig. 12 The initial body surface after addition of internal curves

The front and rear end of the main body are covered by two rectangles which get a curvature connection to the main body surface. Because of the fine connection nothing is done to convert the triangles into more flexible square patches. See fig. 13.

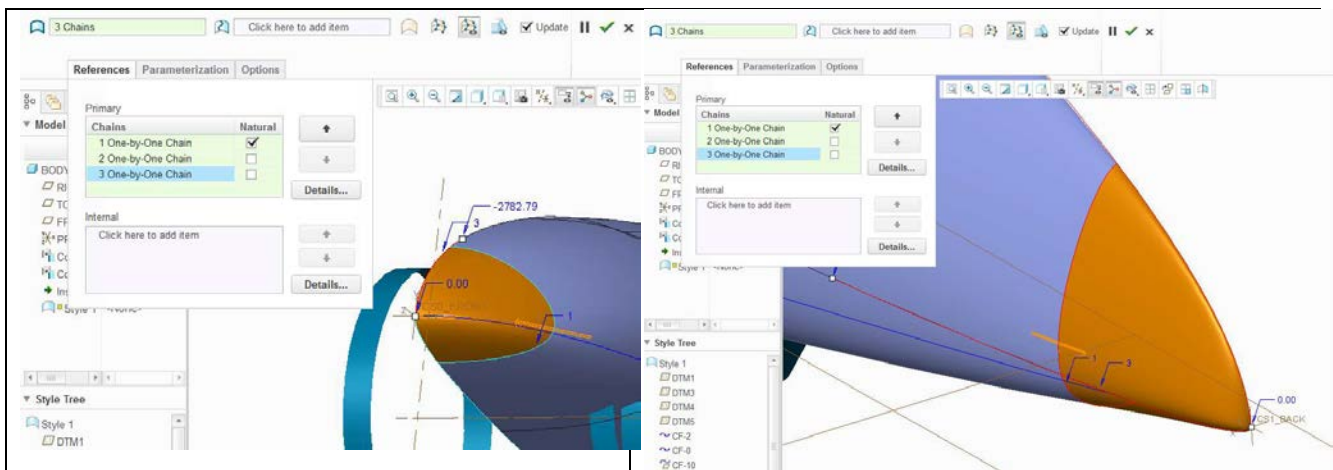


Figure 13 front and rear triangles

Following the initial successful surface design a reflection analysis is in place. The result is shown in fig. 15 As can be seen at the front picture it has been necessary to lift the cross curves around the area of the front wheel to avoid collision between

wheel and fairing. Following this the Mirror/merge/solidify operations create a solid main body (Fig. 16). The solidified surface model is a good test to the quality of the surfaces created. As it is demonstrated the main body consists of three surfaces and the main surface can accommodate design changes by modifying existing curves or by the addition of extra internal curves.

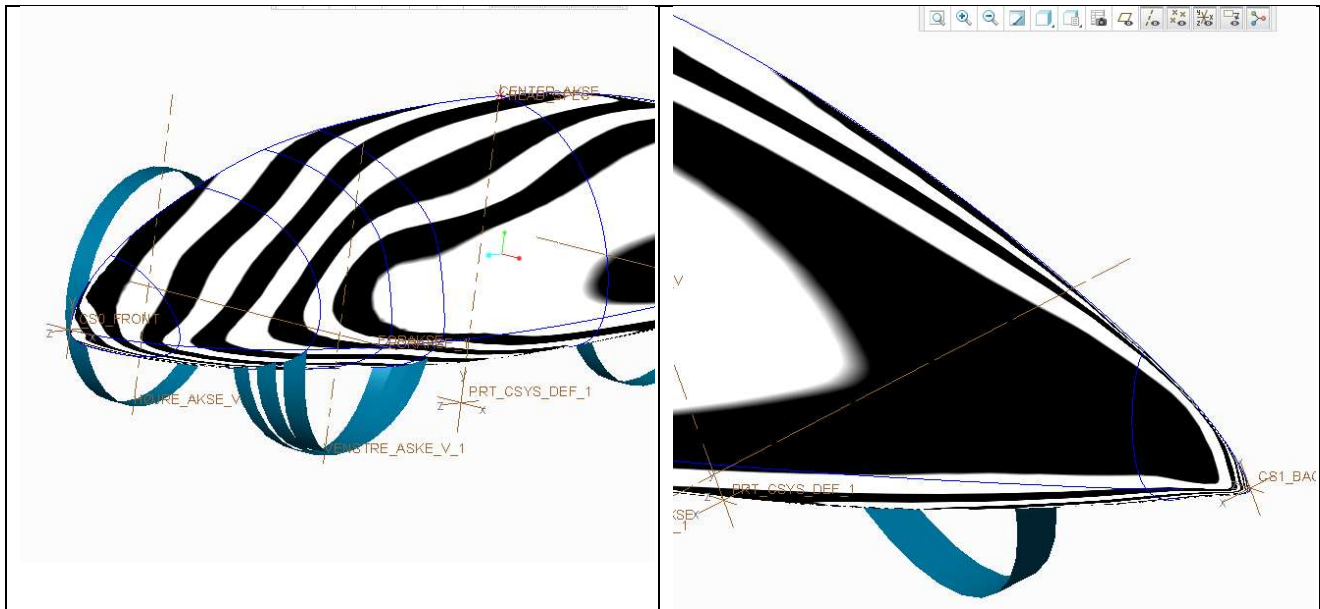


Figure 15 Reflection analysis

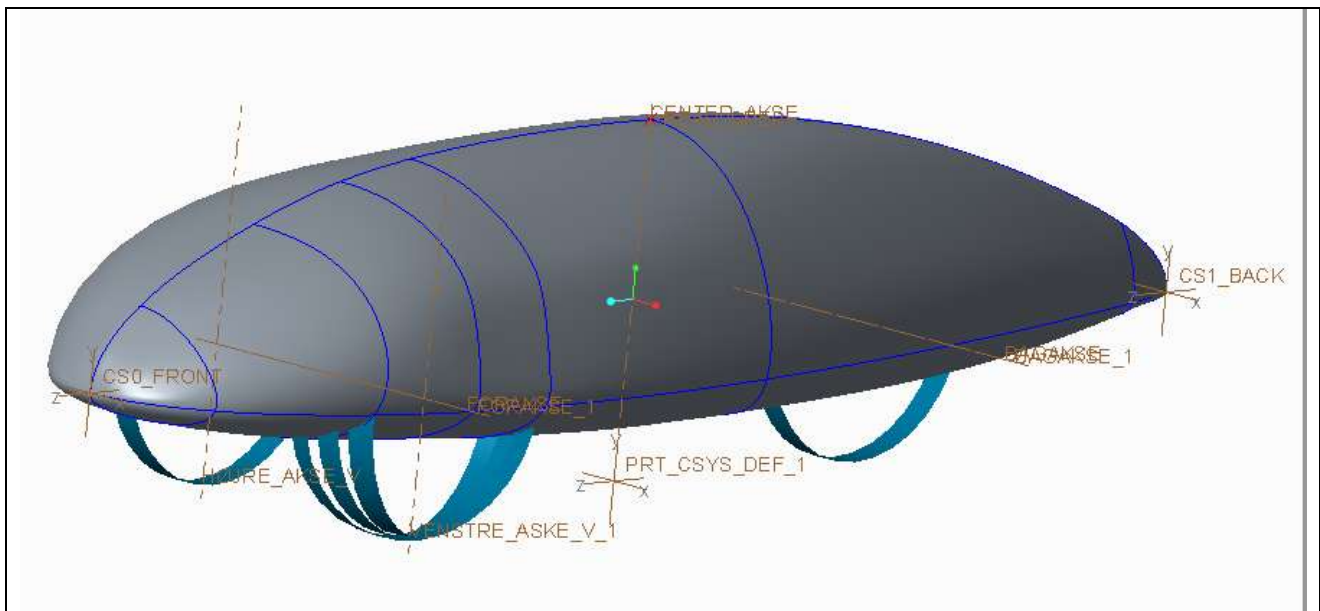
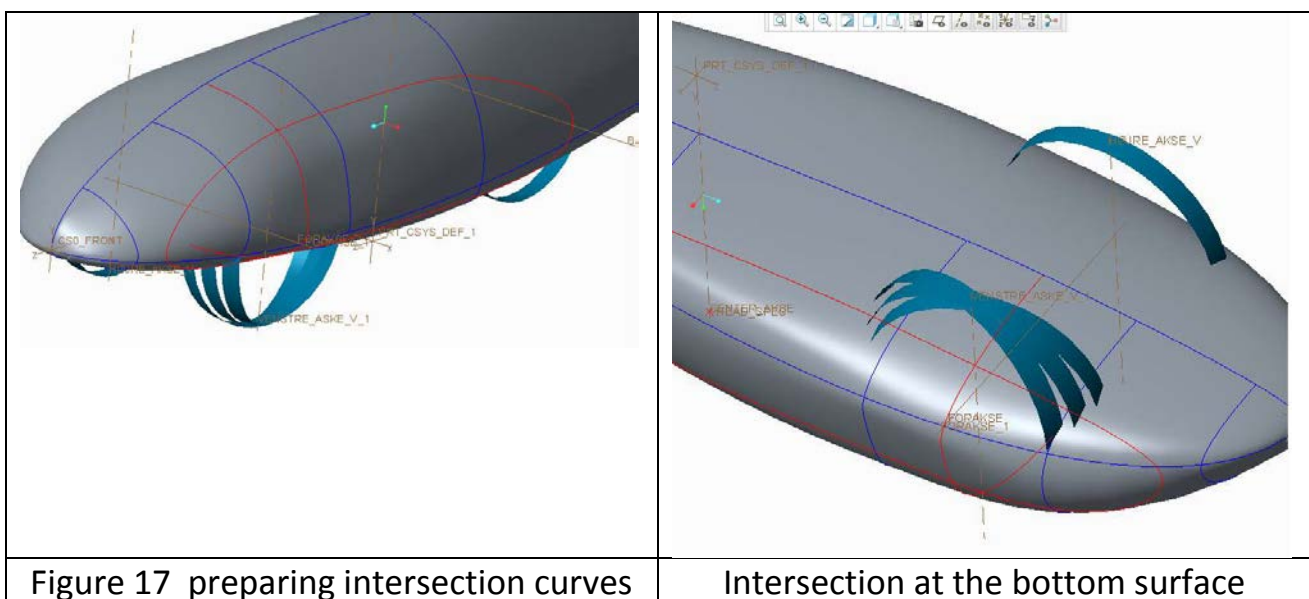


Figure 16 Body solidified

3) The wheel fairings

In preparation to creating the wheel fairing some initial tests have shown that the best procedure is to plan for a section profile drawn directly on the lower surface of the solid body and that this curve should be split into 4 separate segments. The lower part of the wheel fairing can then be drawn, also as style curves on the SKØRT-plane. This curve should be divided in a similar way into 4 segments. The option of projecting a planer curve onto the lower body surface is rejected because the projected curve is divided in a non-controllable way into one or more segments. The modification of the projected curve is also more indirect and cumbersome. As the segment of the SKØRT-curve and the BODY-curve must be connected “vertically” it is an advantage to prepare meeting and connection references. In this case two important intersection curves are created. These are intersection between the body surface and the VENSTRE_ HJULPLAN and the body surface and the FORHJUL_VERTICAL. The intersecting curves can be seen at fig. 17



The STYLE surface creation is shown in fig. 18.

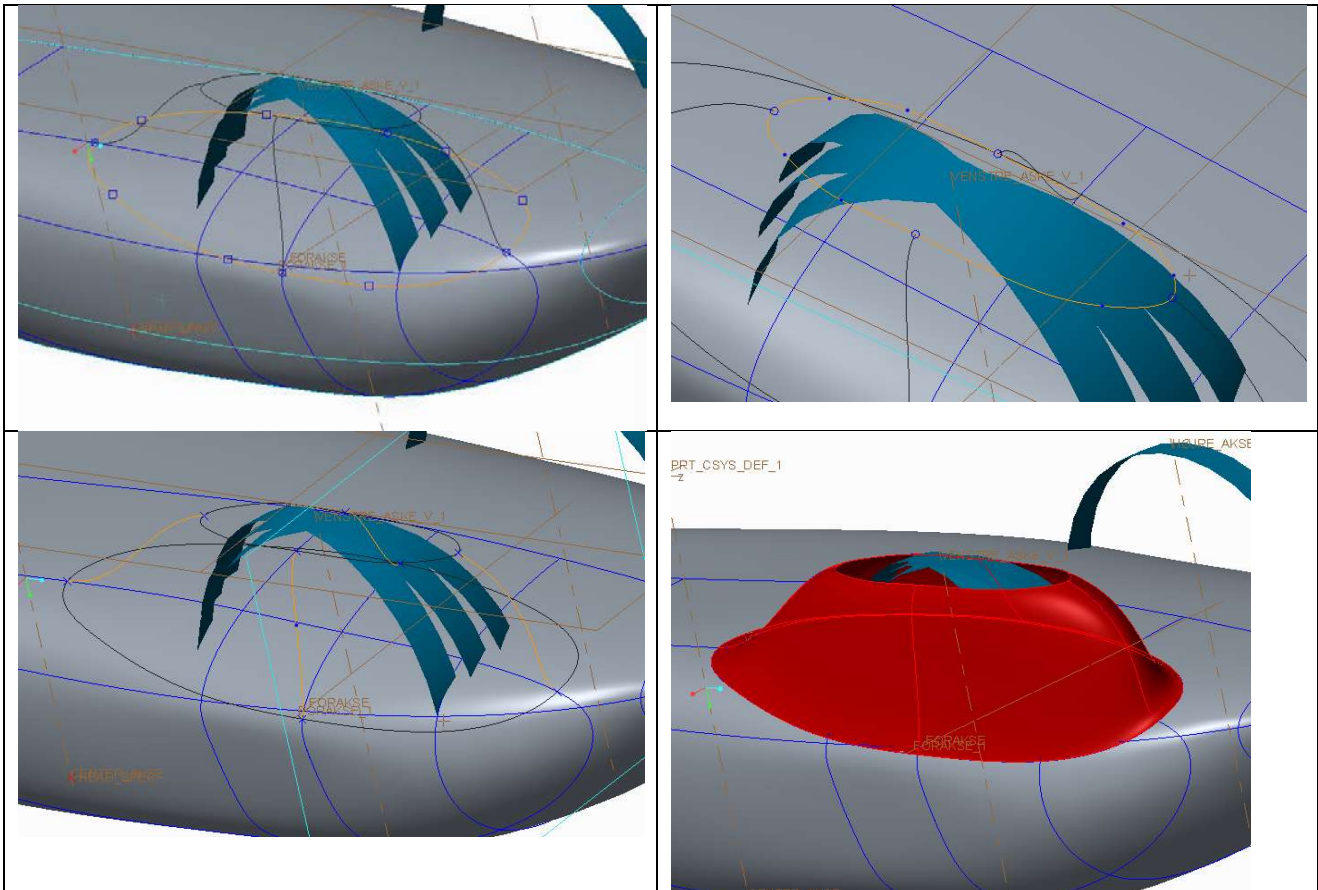


Figure 18 The wheel fairing creation

Intersections with the BODY are illustrated in fig. 19.

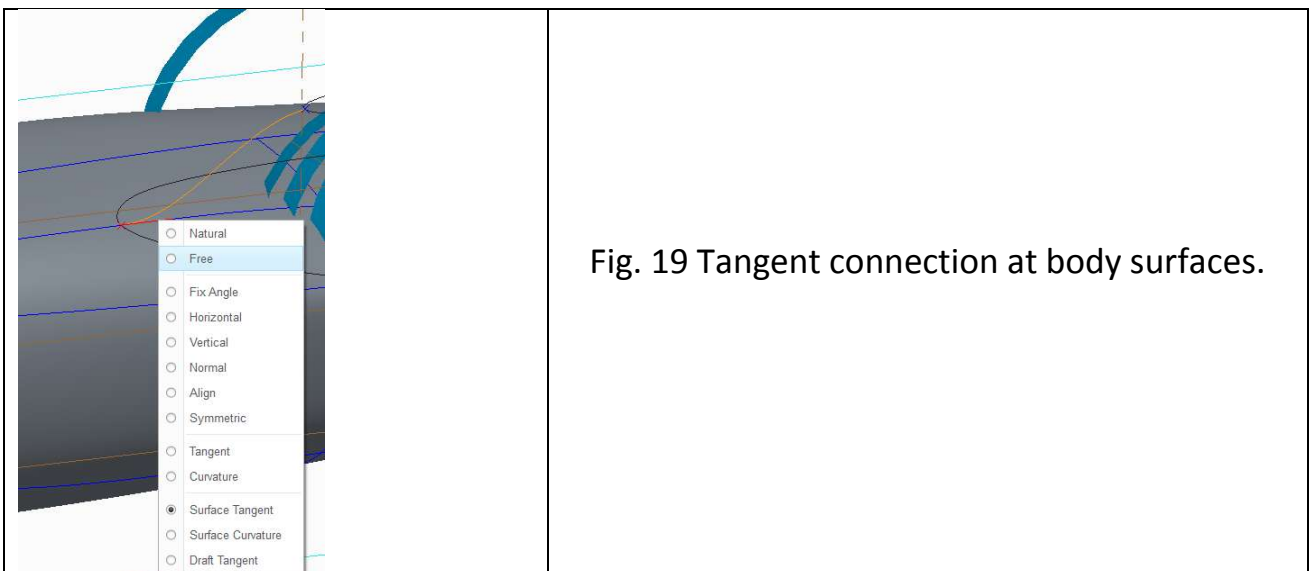


Fig. 19 Tangent connection at body surfaces.

The rear wheel is constructed following the same guidelines. Only half of the casing need to be constructed here because the rest is created by symmetry considerations. Only one interesting curve must be created. The curves and surfaces are shown in fig. 20. Only two surfaces are used. It may be an advantage to change particularly the hindmost surface in future version to achieved better control with the main body.

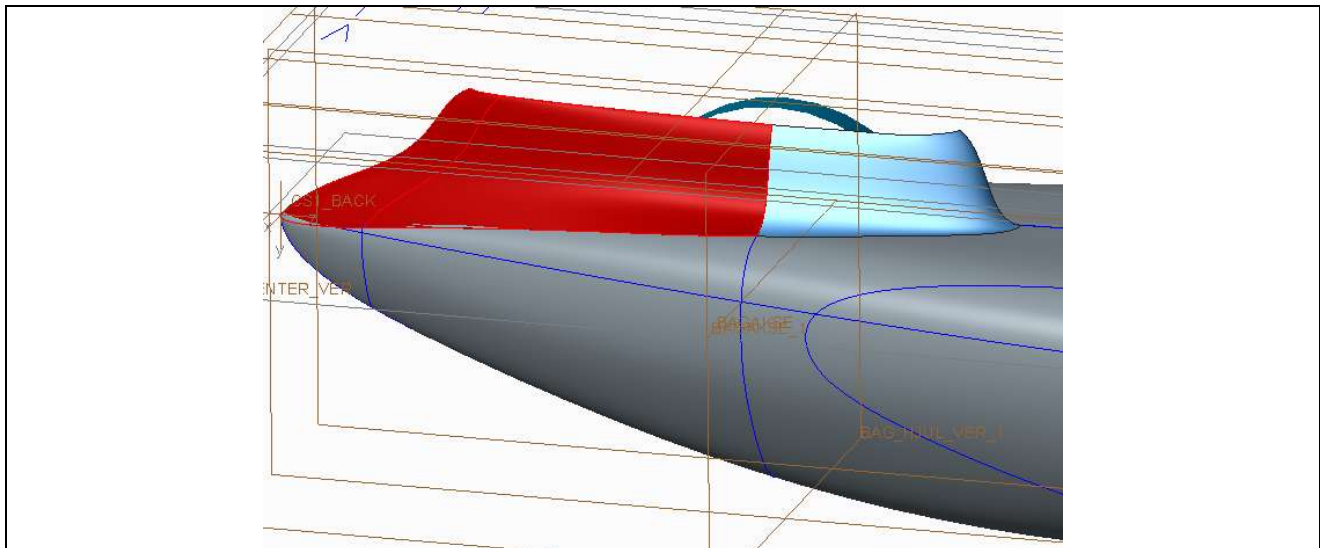


Figure 20 Curves and surfaces at the rear wheel fairing

Additional improvements would be to replace the circular curve on the BODY and the circular curve on the SKØRT-datum plane with “flow improved” versions like NACA-profiles. It is recommended in case such attempts are pursued to divide the NACA profiles into 2/4 segments and attach those segments to the intersecting datum planes: FORHJUL_VER, VENSTRE_HJULPLAN and BAG_HJUL_VER.

After completing the fairing surfaces the bottom of the fairings are closed with a fill surface followed by solidification. The result can be seen in fig. 21.

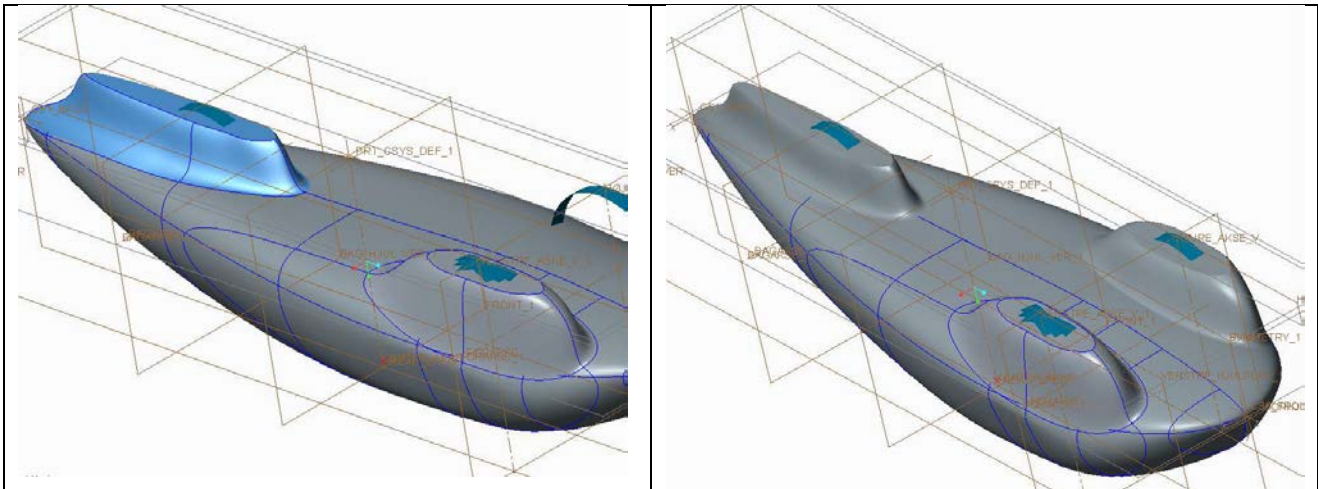


Figure 21 Fill, solidification and mirror operations
(containing 29 features, including 3 style features)

Finally the wheels are made solid if they are to be included in the CFD-model. This is done creating solid wheels using the wheel-surfaces as references. It is possible to round the edges between the fill surfaces and the fairing surfaces if desirable. It might though be better to either include the desired rounding's in the vertical fairing curves or to add them at the final stage using the ROUND feature.

4) Preparation for a ½-model CFD simulation

In order to make a optimization using CFD software the model can be prepared by fist making a solid box which is a model of the “wind-tunnel” volume. Make the volume around a world coordinate system CSO. The placement of the ECO-car model is put into the tunnel by a default assembly operation similar to merging the world coordinate system of the tunnel with the world coordinate system of the Eco-car. The two models must then be assembled and the eco-car model subtracted from the tunnel volume by using COMPONENT operations. The resulting flow simulation volume is shown in fig. 22. Here half of the model is removed by a simple

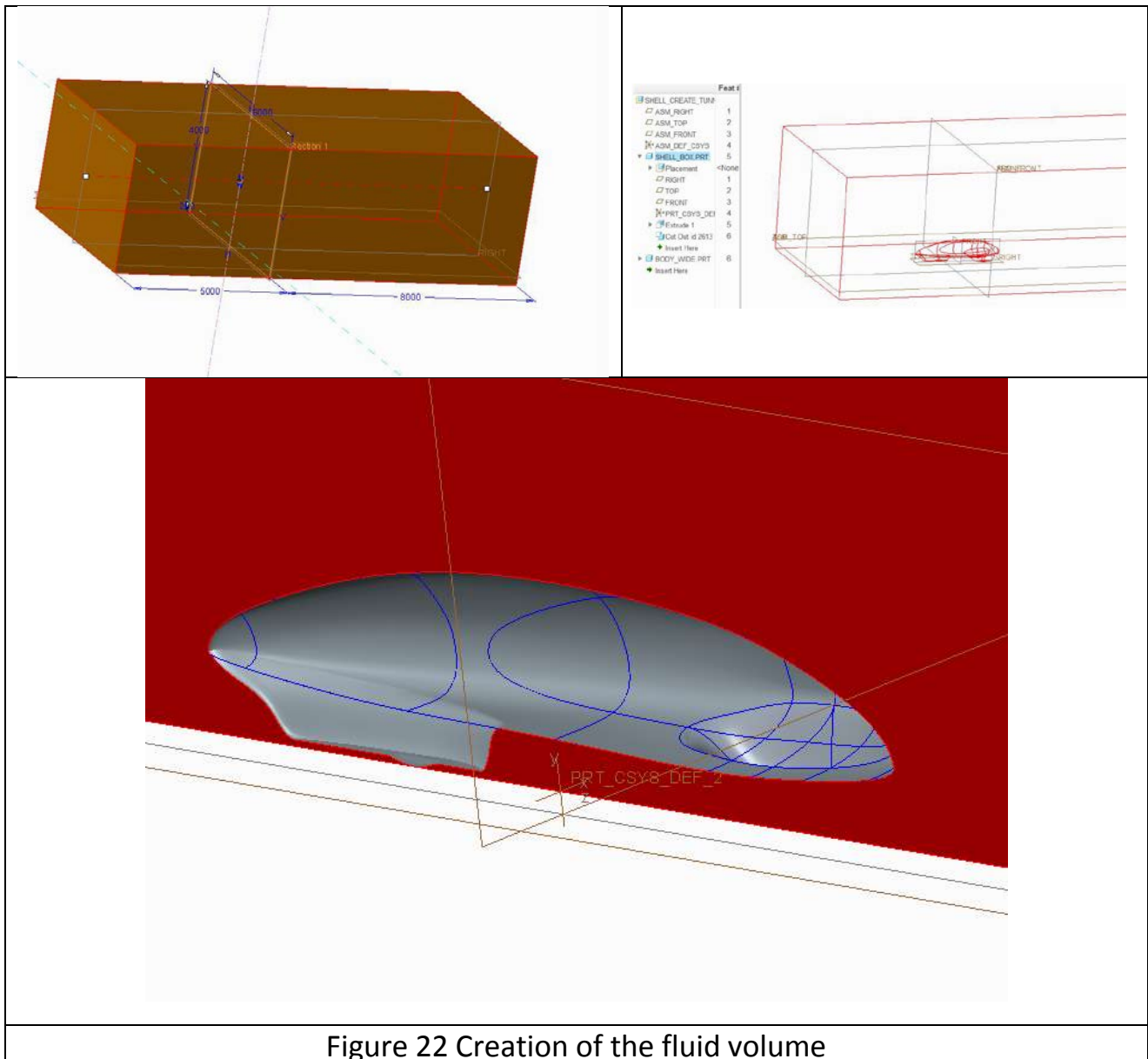


Figure 22 Creation of the fluid volume

extrude operation. Depending on the CFD software the model is saved in e.g. STEP- or stl-format. Initial simulations were done using AUTODESK Simulation CFD 2015 [ref. 7]. A result from this type of simulations is shown in fig. 23. An optimization was however not undertaken primarily because of little prior experience with the software and the requirement of accurate and stable calculations that require large amount of time and computational power.

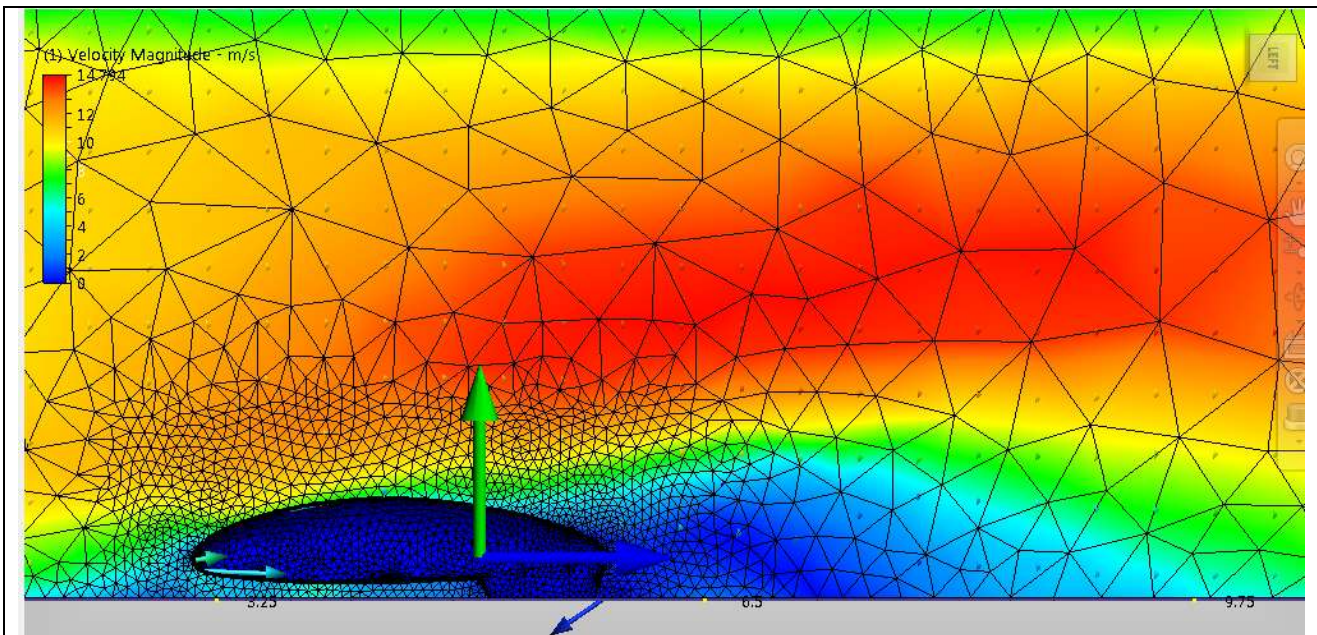


Figure 23 CFD results from AUTODESKS simulation CFD 2015 with ECO-car body

5) Flexibility of the model

As noted in relation to the import of NACA-curves the flexibility is limited. This limitation has however been investigated to overcome the problem. It is desirable to make investigations on a small setup. The setup will be called NACA demo.

Create: NACA demo-part. Get Data and Import the file: airfoil3Z.ibl. See fig. 24. You must now accept the curve selection as polygonal curve.

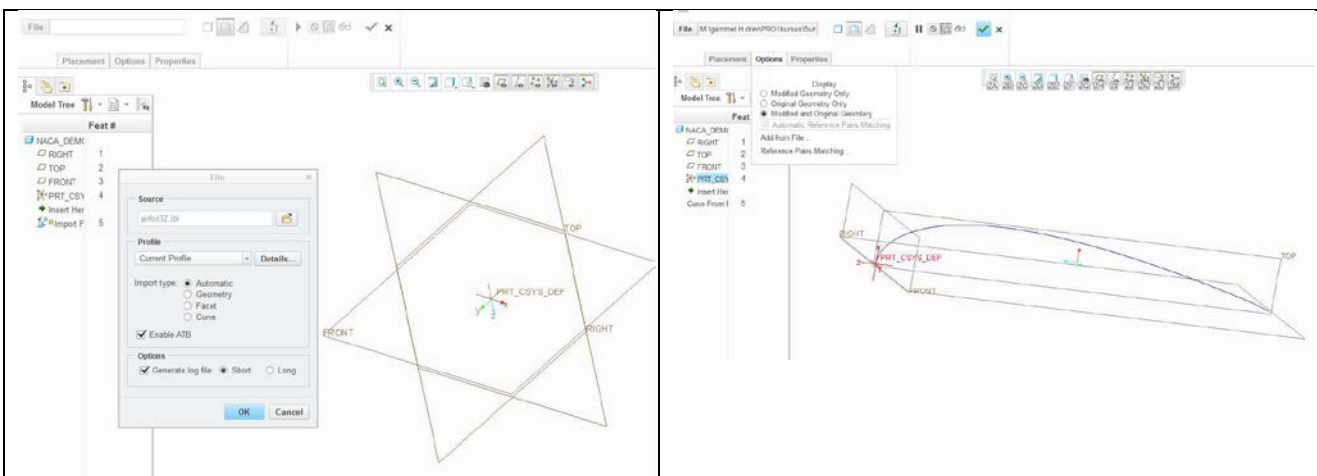


Figure 24 Import of NACA points as curve

Proceed to import another curve using the same Import feature. Click: Add From File and select the file: airfoil3Z_man. See fig. 25. Accept the Import Data feature.

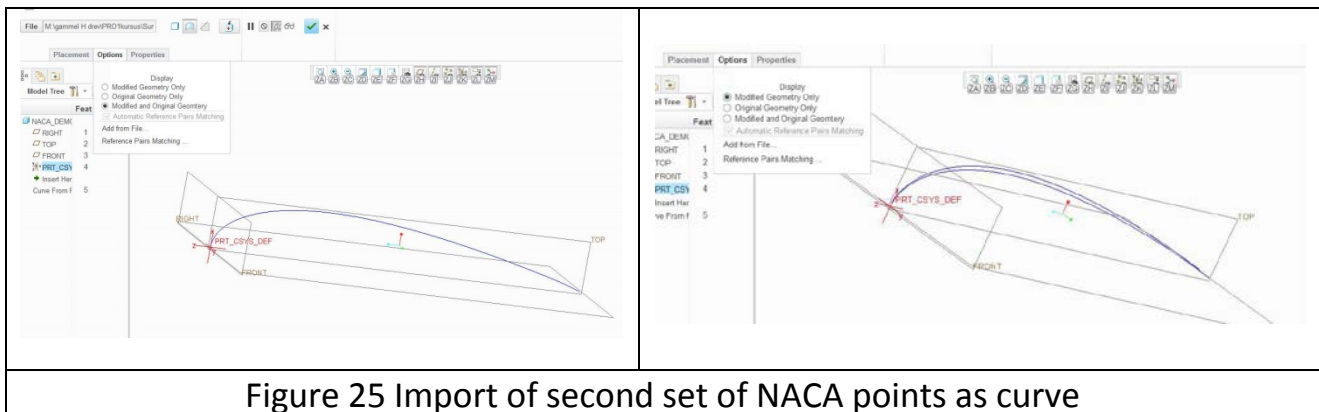


Figure 25 Import of second set of NACA points as curve

Insert a Style feature. Inside Style make a new planar curve on the same plane where the import curves are. Connect the planar curve to the inner curve (with the smallest X-values) and make a surface using the import curve and the new style curve. See fig. 26. Notice that the style curve is referencing the imported curve – for now the curve with smaller x-values: the inner curve.

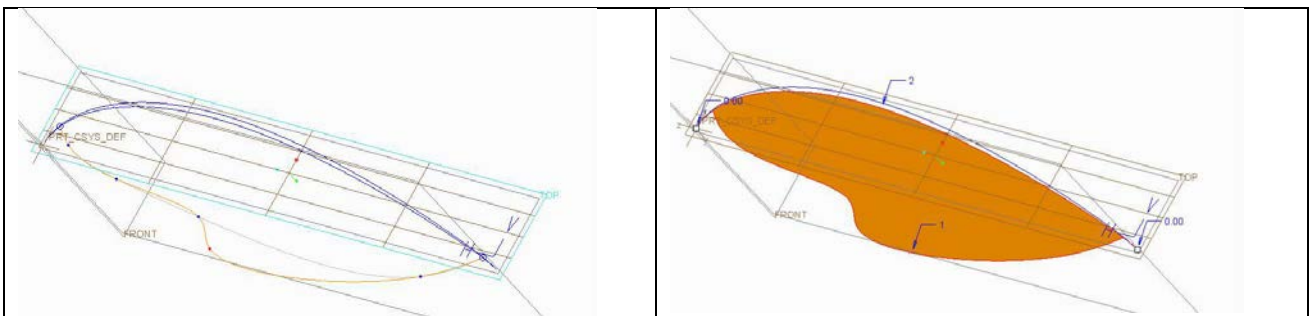
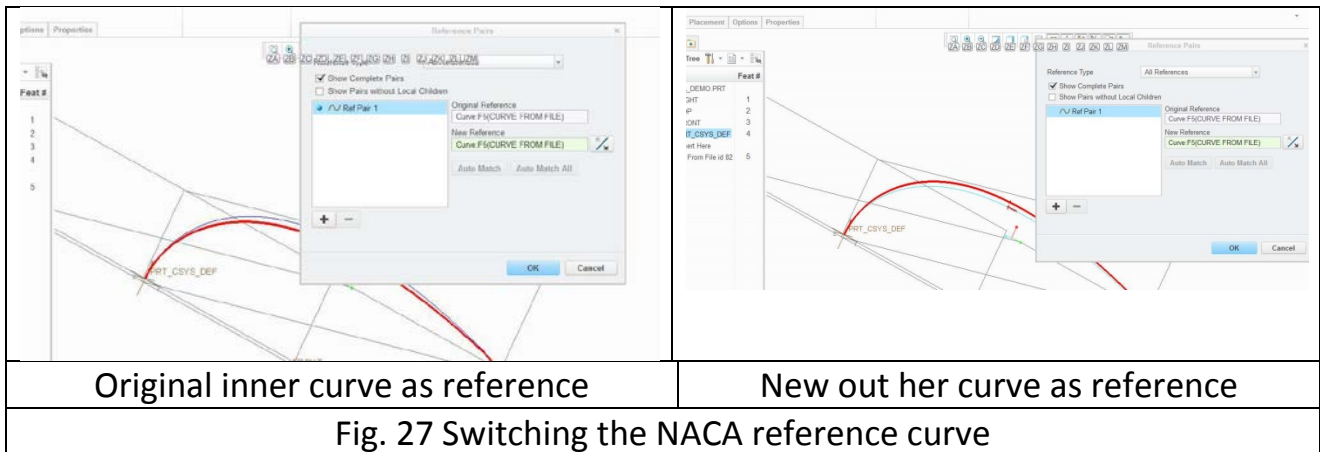


Fig. 26 Creation of style feature and surface

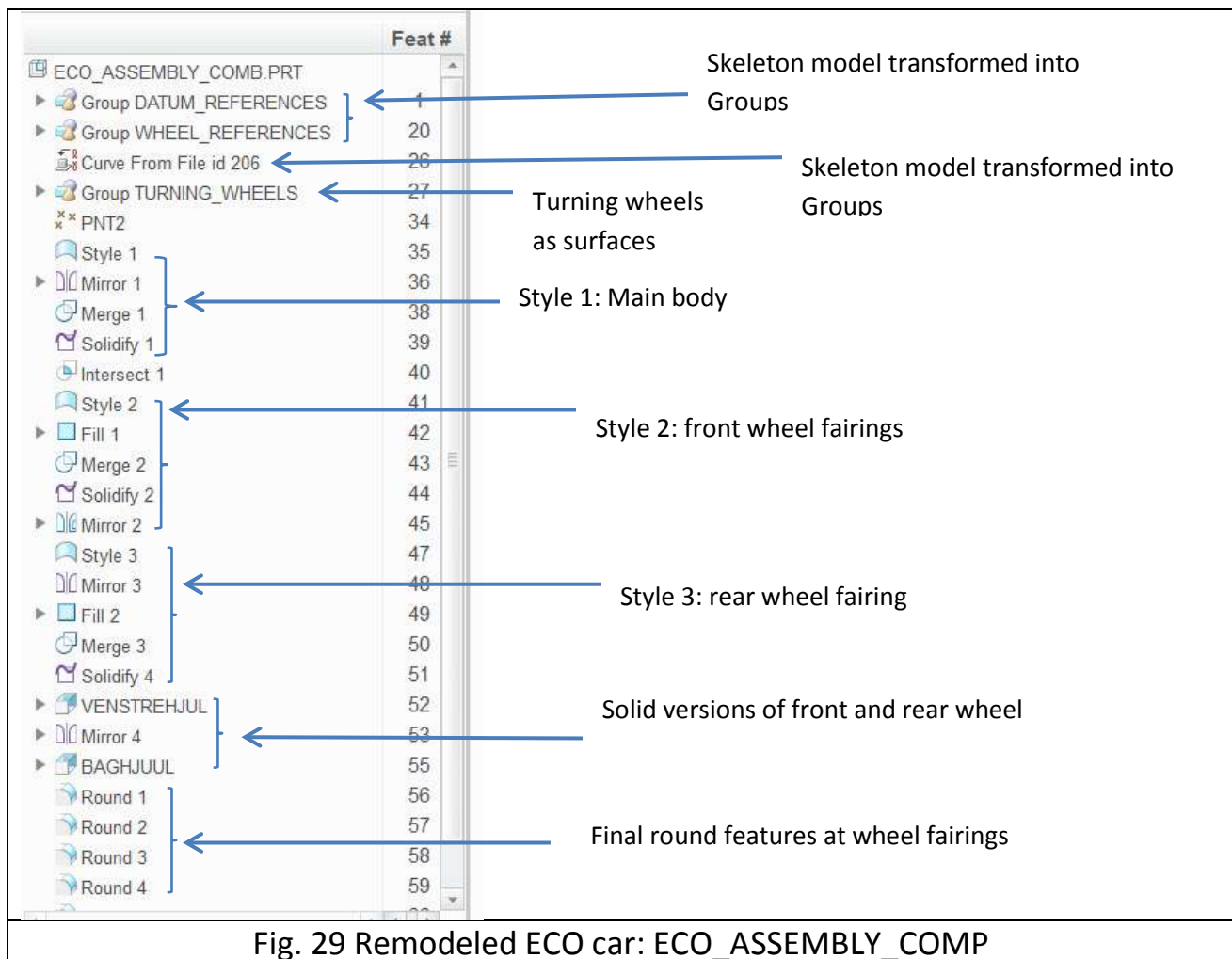
We now edit the Import Data –feature: Curve from File. In the Options list select: “o Modified and Original Geometry” and “Reference Pairs Matching”. Click at “Show Complete Pairs” and click at “Ref Pair 1”. See fig. 27. Notice that the inner curve is highlighted as “New Reference”. If you want to change this RMB and select: Remove. Now switch off the “Show Complete Pairs”. The uncomplete pair “Ref Pair 1” is now shown again. This time insert the outer curve and once again switch on the “Show Complete Pairs”. Accept the feature and if successful watch the reference, curve and surface update in the STYLE feature. See Fig. 28.



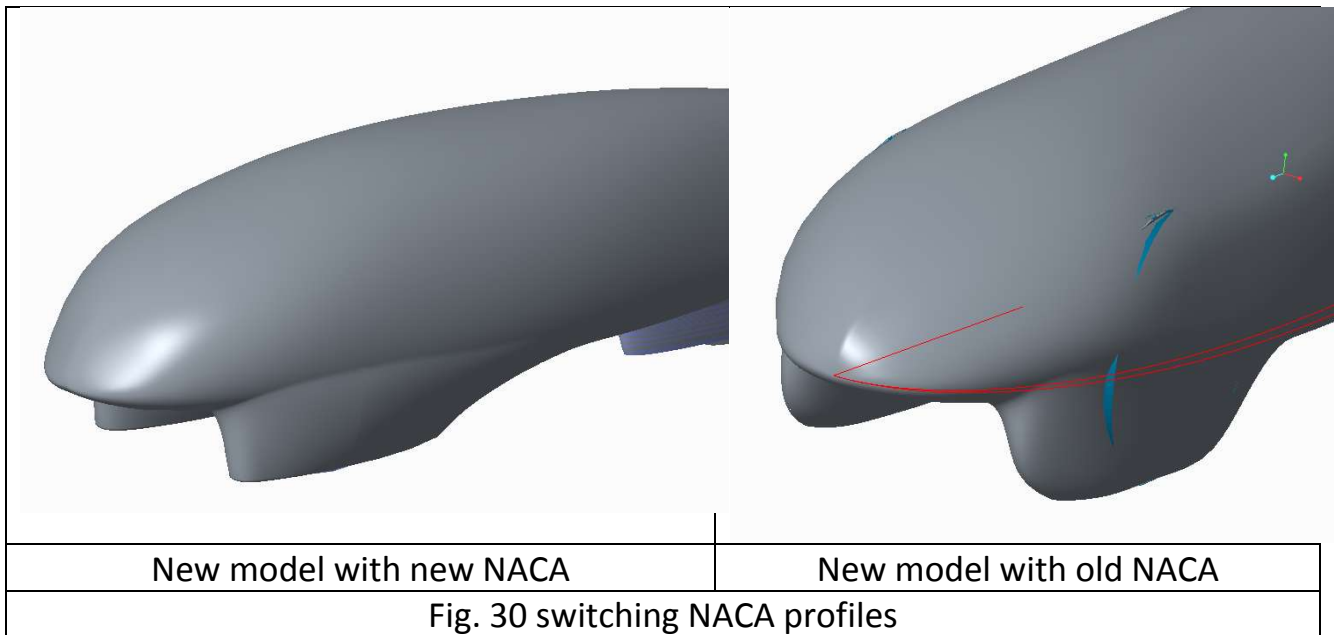
This should overcome the limited ability to change imported curve data. The reason for this exercise and demo is that is quite “tricky” and you should practice it before you try to exercise it on the CFD-model as it has quite fundamental impact on the total model.

5) Moment of truth

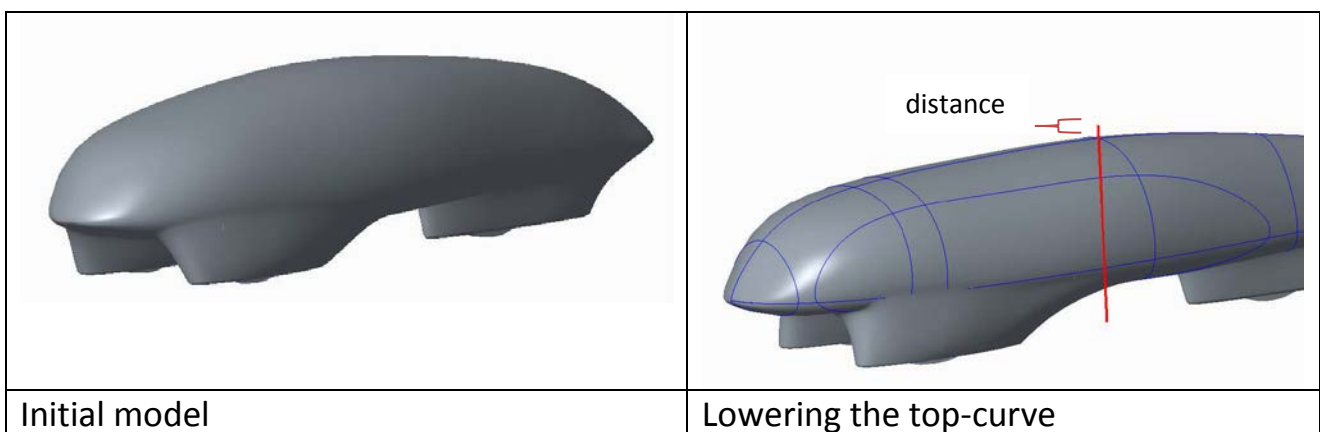
In the following process it was tested whether this could work for the present assembly model. It worked for the skeleton model – but only on conditions where the NACA curves were actually references by other features. As a test a surface as shown in fig. 28 were constructed as a dummy feature to create such referencing. Making a switch between the old and the new NACA curves was working. The propagation to the Public feature failed however and even when this reference problem was solved manually the consecutive COPY operation in the part: BODY_wide failed. In both cases references were lost and consecutive feature were failing. At the time of this report no solution with the Top-down structure was found. Therefore it was decided to make a one part solution. This was done using the skeleton model: ECO_ASSEMBLY_SKELETON1.prt with the reference stuff and curve import and save it as a new part: ECO_ASSEMBLY_COMP. The modeling of the main body and the fairings had to be done by scratch. In order to keep the model tree manageable a number of features were grouped as seen in fig. 29



This transformation helped the model become flexible also with regard to the NACA profiles. Two examples where the NACA profile was switched from new to old profile is shown in fig. 30.



The remaining model can be optimized with care using the interactive style curves used for this part of the model. Some examples of this are shown in fig. 31. In many cases the fairings alter shape as a consequence of Main body changes. In most cases this can be handled by sub sequentially modifying Style 2



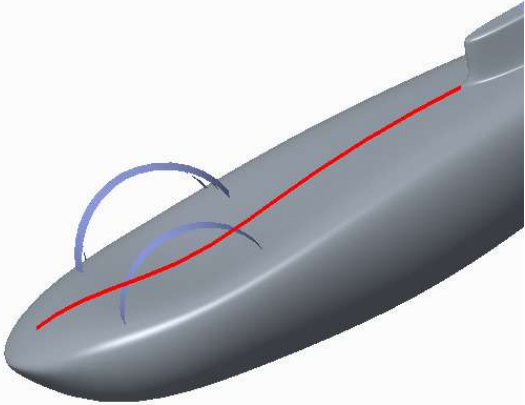
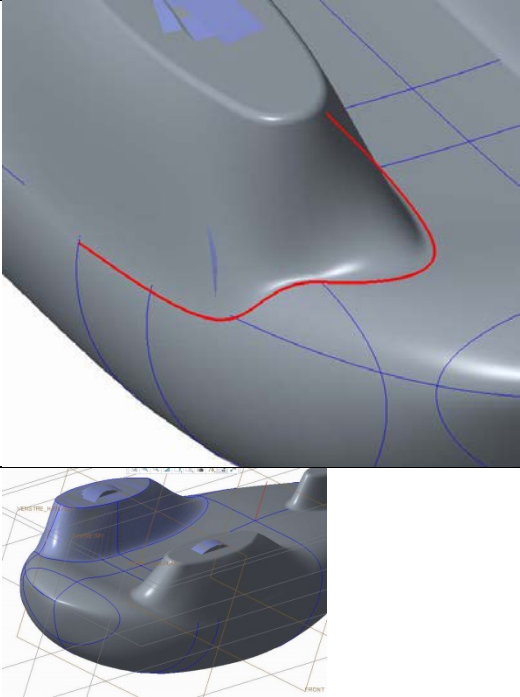
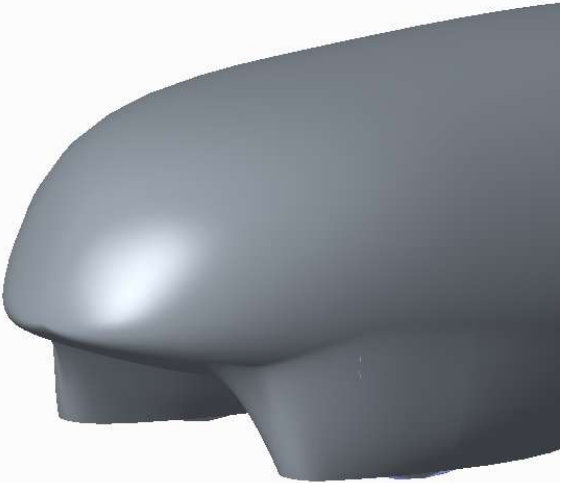
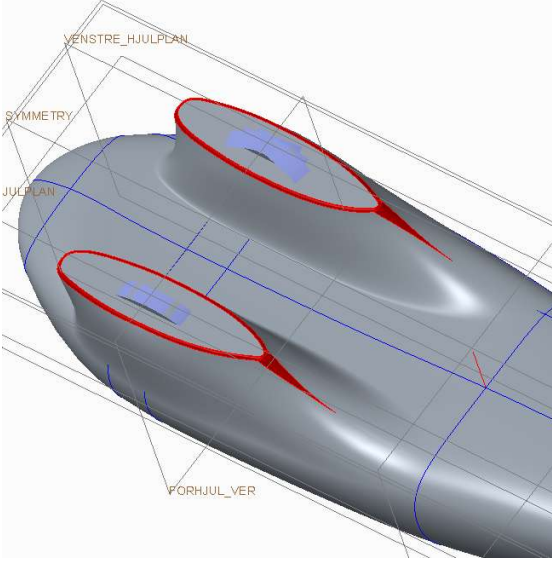
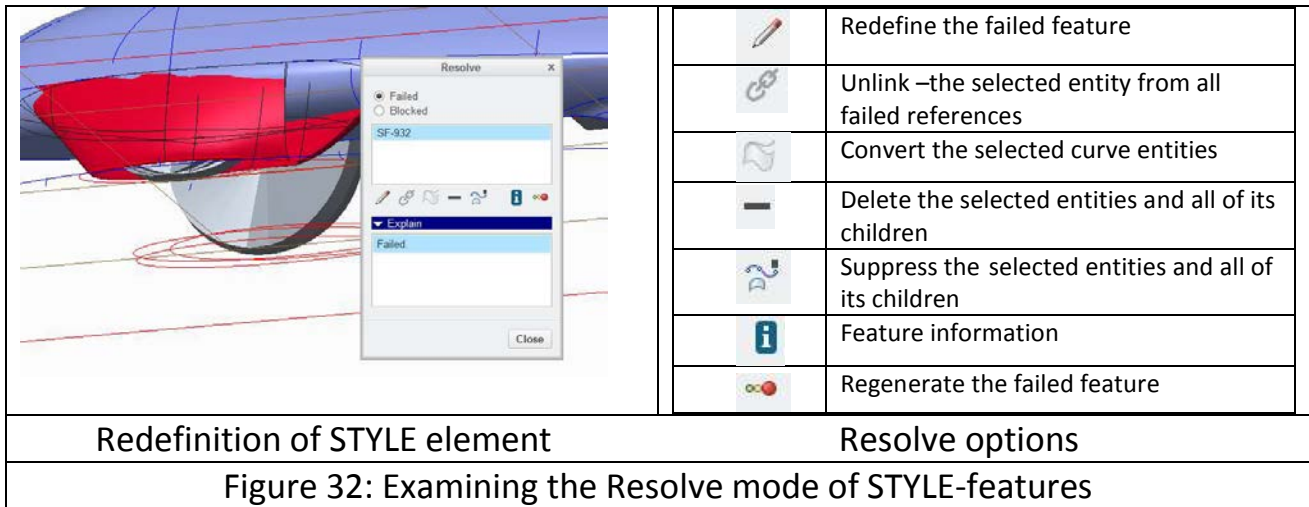
| | |
|--|---|
|  |  |
| Lifting the bootom curve between fairings | Fairing needs curve modofication |
|  |  |
| Changing the front | Redefining the final rounds |
| Figure 31 Editing the final model | |

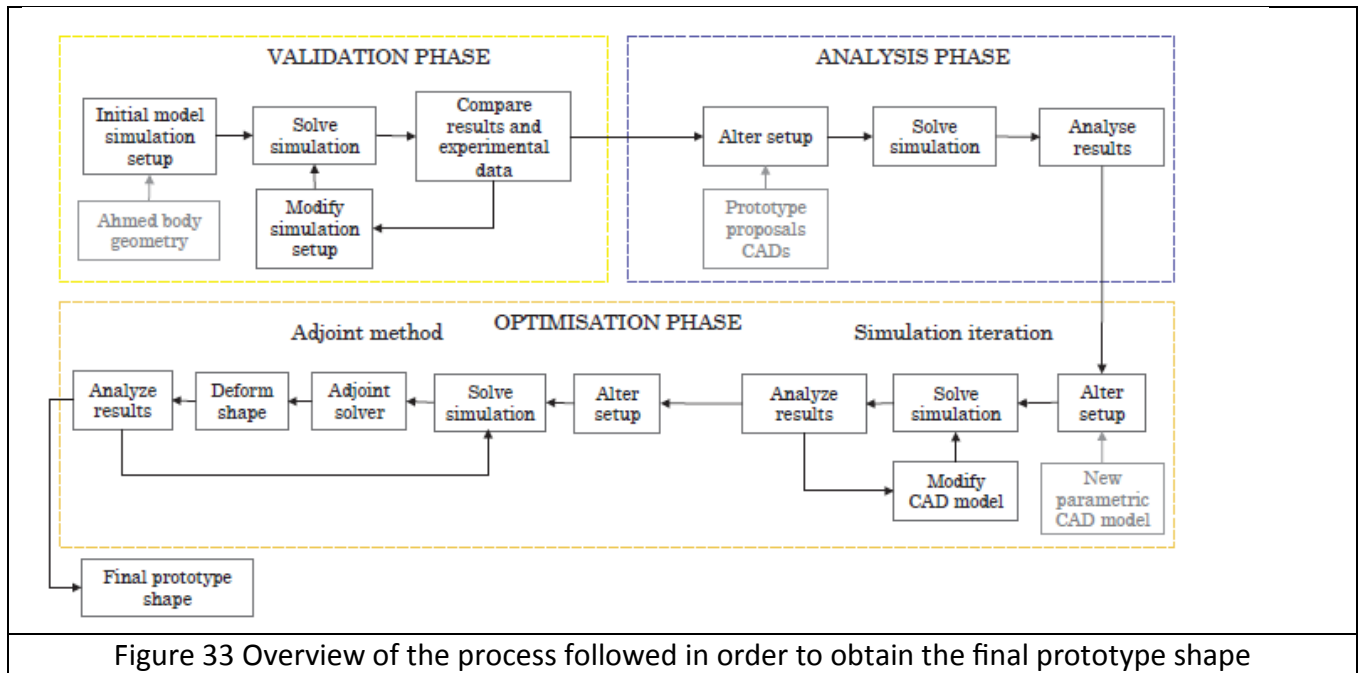
Figure 31 show some examples of modifications carried out on the model. As it can be seen some modifications of the Main body may require modifications or even error corrections on the front wheel fairings. Also the rounds at the fairing top seem to be quite fragile. They are however late in the model tree and can be redefined without much effort. With this model it is often possible to resolve by

examining the options in the STYLE Resolve mode. See fig. 32 where the Resolve mode is active on the original model.



6) Conclusions

The benefit of the current surface model must be proved by future utilization of optimizations using CFD-software. [ref. 8] The process cycle used by Neus M. Teixido [ref. 3] is illustrated in fig. 33. The software can automatically make computations in order to find lower flow resistance shapes. Unfortunately at the present state the model cannot be transferred back to the CAD system, so that the optimized model can be used for the manufacturing process required. Therefore the optimization will have to be carried by “hand” from the CFD-calculations to the modification of the CAD model. Future improvements where data can be brought back to the CAD model is initiated by the demonstrated import and modification of NACA-curves. This opens the possibility that point sets (creating curves) can be imported from CFD calculations if geometry data from CFD can be achieved.



References

Reference 1: private conversations with: Sigurd L. Ildvedsen and other Eco team members

Reference 2: <http://www.shell.com/global/environment-society/ecomarathon.html> (accessed 21. of January 2016).

Reference 3: Neus Mesalles Teixidó "CFD analysis and optimization of aerodynamics on a fuel efficient vehicle", Juli 2015, DTU Mekanik.

Reference 4: <https://upload.wikimedia.org/wikipedia/commons/thumb/3/37/14ilf1l.svg/220px-14ilf1l.svg.png> (accessed 19. of January 2016)

Reference 5: NACA airfoils at: <http://airfoiltools.com/airfoil/details?airfoil=naca0015-il> (accessed 21. of January 2016).

Reference 6: private conversation with: Professor MSO: Jens Honore Walter, DTU Mekanik

Reference 7: "Autodesk Simulation CFD 2015"- help functions inside software, AUTODESK

Reference 8: CD-Adapco. "STAR-CCM+ Manual", version 10.02.012 edition

Appendix A:

The IBL-file to be imported directly as a spline into Creo.

open

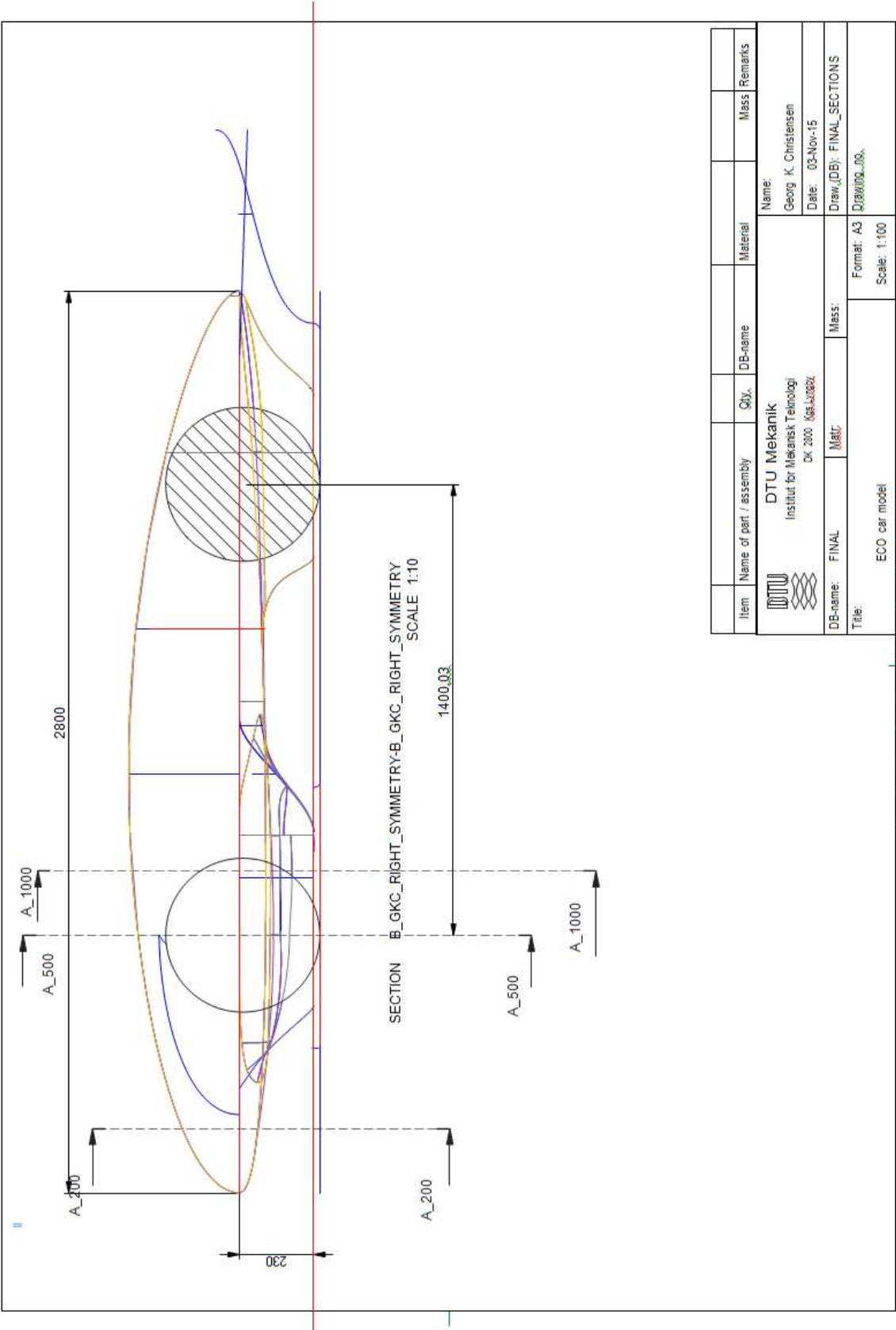
arclength

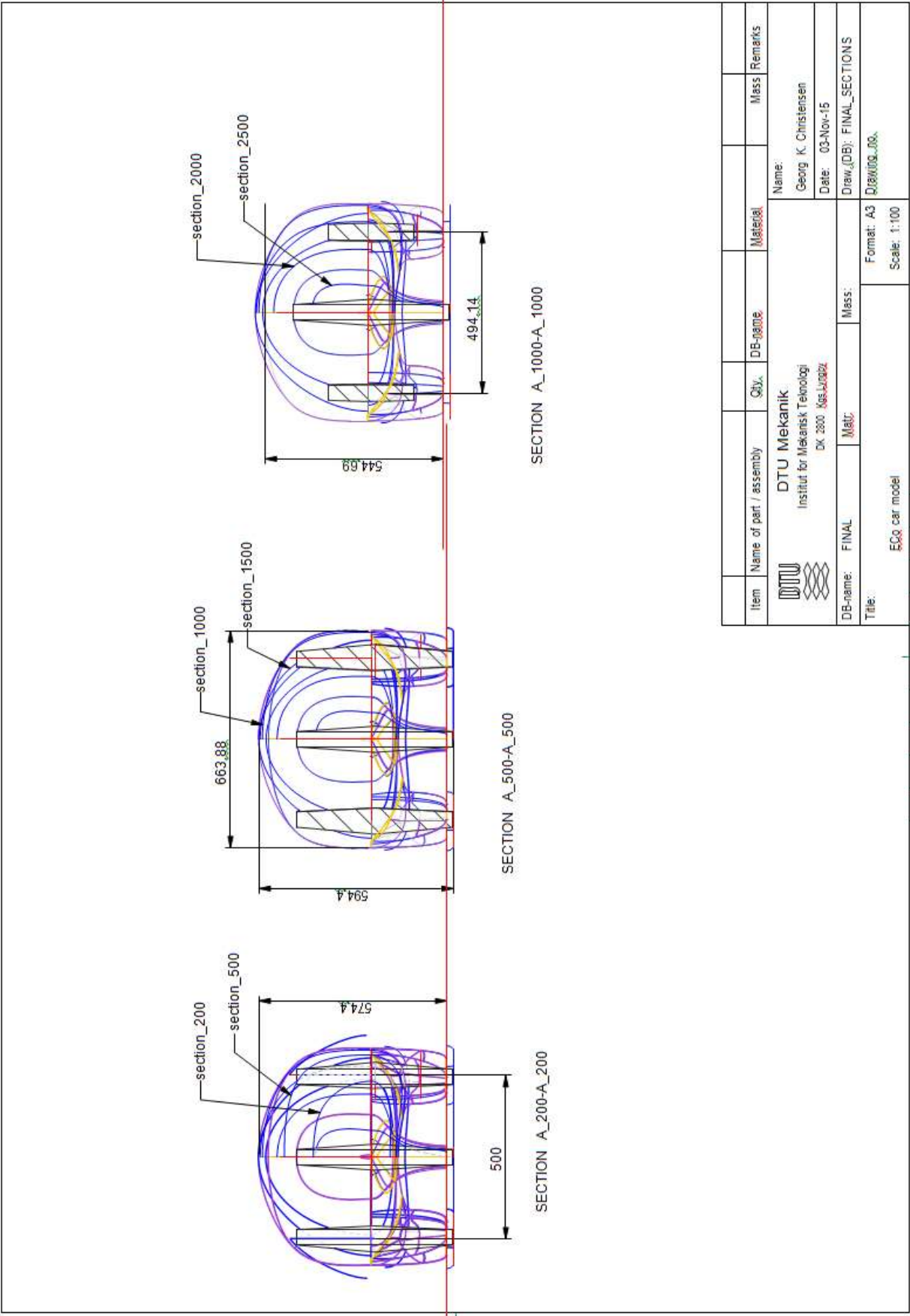
begin section ! 1

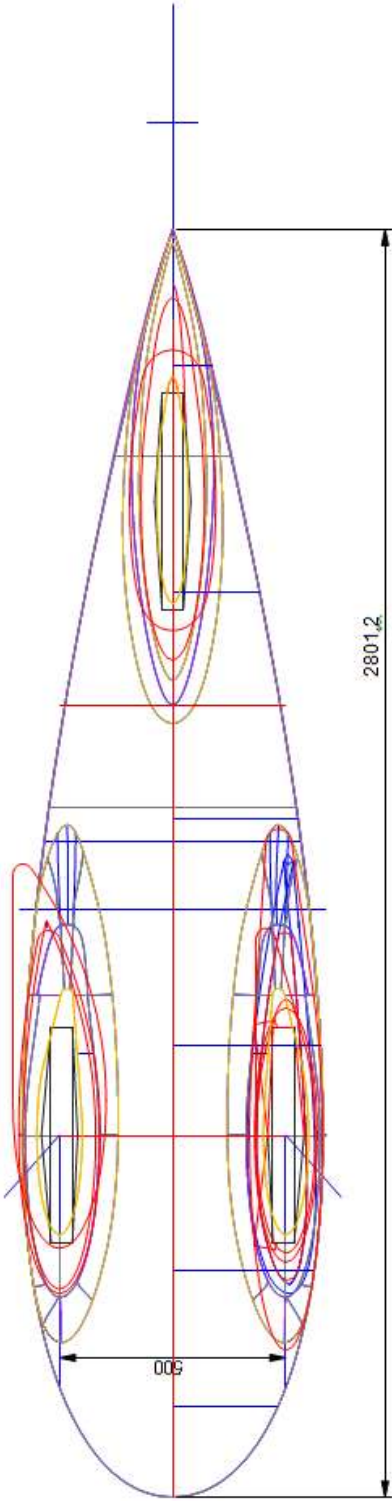
begin curve

| | | | |
|----|---------|---|-------|
| 1 | 0 | 0 | -2800 |
| 2 | 47.376 | 0 | -2660 |
| 3 | 85.07 | 0 | -2520 |
| 4 | 154.113 | 0 | -2240 |
| 5 | 215.26 | 0 | -1960 |
| 6 | 268.088 | 0 | -1680 |
| 7 | 310.999 | 0 | -1400 |
| 8 | 340.938 | 0 | -1120 |
| 9 | 352.594 | 0 | -840 |
| 10 | 349.069 | 0 | -700 |
| 11 | 337.084 | 0 | -560 |
| 12 | 314.054 | 0 | -420 |
| 13 | 275.091 | 0 | -280 |
| 14 | 246.75 | 0 | -210 |
| 15 | 208.821 | 0 | -140 |
| 16 | 153.596 | 0 | -70 |
| 17 | 111.249 | 0 | -35 |
| 18 | 0 | 0 | 0 |

Appendix B (drawing from the received model)







| Item | Name of part / assembly | Qty. | DB-name | Material | Mass | Remarks |
|--|-------------------------|---------------|---------|-------------------------------|------|---------|
| <div><div></div><div>DTU Mekanik Institut for Mekanisk Teknologi DK 2800 Kgs. Lyngby</div></div> | | | | | | |
| DB-name: FINAL | | Matr: | Mass: | Name: Georg K. Christensen | | |
| Title: | | ECO-car model | | Date: 03-Nov-15 | | |
| | | | | Draw.(DB): FINAL_SECTIONS | | |
| | | | | Format: A3 | | |
| | | | | Scale: 1:100 | | |
| | | | | Draw.(DB): 000 | | |